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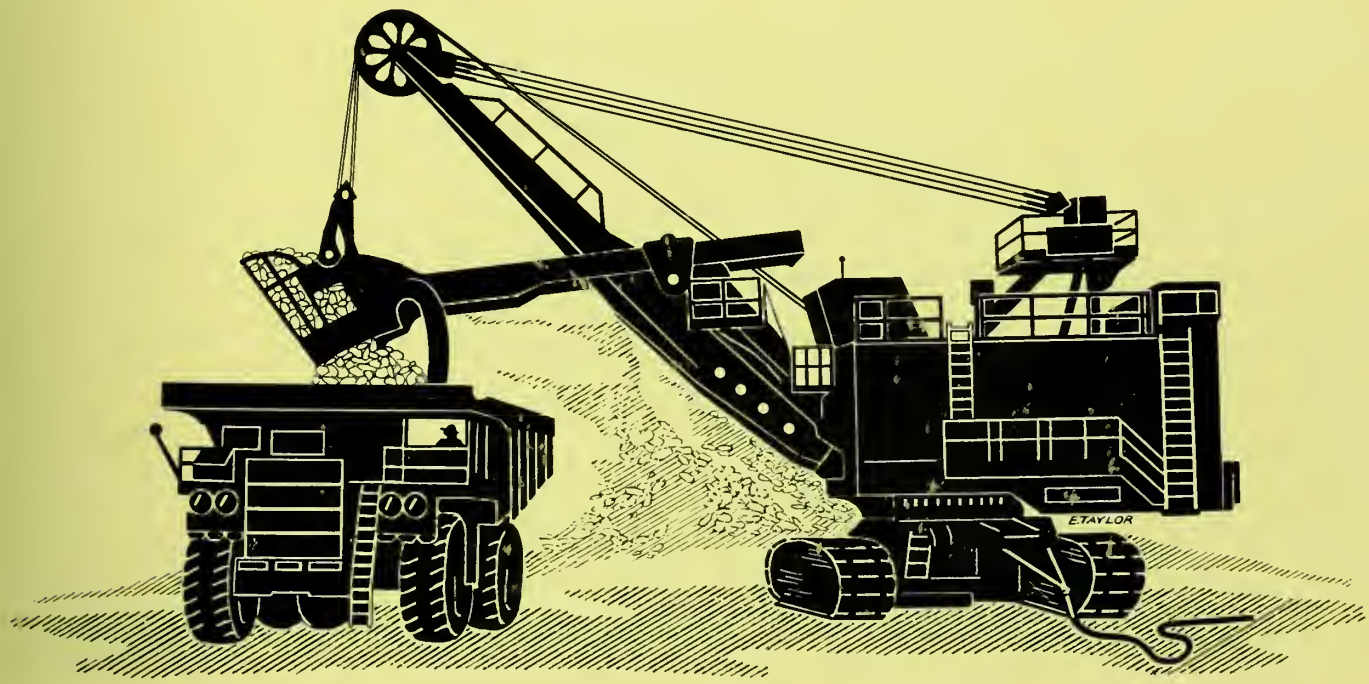

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MINERAL COMMODITY REPORT:

BENTONITE AND FULLER'S EARTH

1990

By

Michael A. Silva
and
Daniel T. Eyde

Part 1 from
the U.S. Bureau of Mines publication,
Mineral Commodity Summaries, 1990

CALIFORNIA DEPARTMENT OF CONSERVATION
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INTRODUCTION

This report on the availability and demand for bentonite and fuller's earth in California, the United States and the world is one in a series of Mineral Commodity Reports prepared by the Department of Conservation, Division of Mines and Geology (DMG) to describe mineral commodities of significance to California and the nation.

This mineral commodity report was compiled by Michael A. Silva of the DMG geologic staff and Daniel T. Eyde of GSA Resources, Inc., in Cortaro, Arizona. Part I consists of United States and worldwide mineral statistic information and analysis adopted directly from the U.S. Bureau of Mines "Mineral Commodity Summaries, 1990." Part II discusses

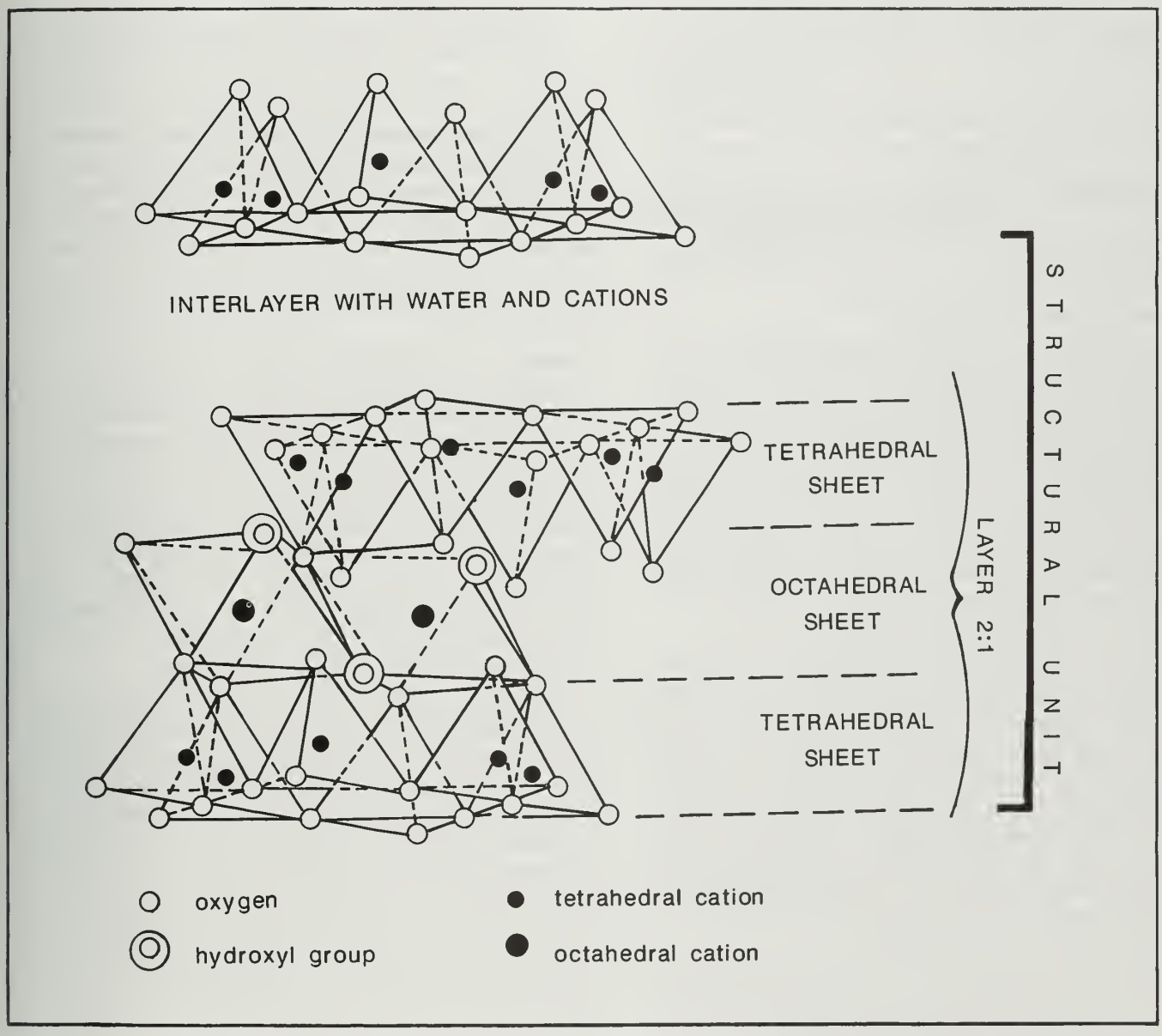


Figure I. Tri-dimensional sketch of the structure of the smectite group of clay minerals (Chamley, 1989).

production of bentonite and fuller's earth in California. The U.S. Bureau of Mines presents the earliest yearly government estimate of non-fuel mineral industry data, including world resource data provided by the U.S. Geological Survey. Bentonite and fuller's earth are included in the clay report.

Clays, as industrial minerals, are generally organized into the following categories: 1) bentonite and fuller's earth; 2) kaolin, ball clay, fire clay, halloysite; and 3) shale and common clay. In the clay industry, terminology is often difficult to understand, because terms used to describe clays are derived from uses, geologic origin and mineralogy. "Fuller's earth" is a use term that originated in Great Britain. Clay materials or "earths" used by fullers to full woolen fabrics (shrink and thicken by application of moisture) came to be known as fuller's earth. Worldwide, fuller's earth is composed of attapulgite, kaolin or montmorillonite. "Bentonite" is a rock term used to describe deposits of clay minerals with certain physical characteristics. The name was suggested by Knight (1898) for a claylike material with soapy properties mined from the Fort Benton Formation in Wyoming. It was later noted that this clay was formed by devitrification of volcanic ash, and this origin was included in early definitions of bentonite (Grim and Güven, 1978).

For the purposes of this paper, bentonite is defined as any clay that is composed dominantly of a smectite clay mineral and whose physical properties are dominated by this clay mineral, regardless of origin. Smectite is a class or group of clay minerals, formerly called the montmorillonite group. Montmorillonite is a clay mineral and a member of the smectite group of clay minerals. Other smectites include hectorite, saponite and nontronite. Fuller's earth is defined here as a bentonite that has adequate absorbing, decolorizing, and purifying properties. Fuller's earths known in California are composed of montmorillonite (see glossary of terms).

Smectites, the dominant clay minerals that give bentonite its properties, are multi-layered clays, composed of two tetrahedral sheets (dominated by tetrahedral structures of the formula T_2O_5, T being silicon, aluminum or iron) and one octahedral sheet (with medium-sized cations at the center, usually aluminum, magnesium or iron and eight oxygens at the corners). The three sheets are bound together by the oxygen atoms shared by the adjacent tetrahedral and octahedral sheets. Together, these layers form a structural unit of the clay. Cations, usually sodium or calcium, are bound with water in the space between the layers (Figure 1).

Smectites vary in composition through substitution of ions in the structure. When magnesium or another bivalent element is dominant, all cation positions are filled; this type of mineral is called trioctrahedral. When aluminum or another trivalent element is dominant, only two-thirds of the cation positions are filled. This type is dioctrahedral. Intermediate forms do not occur. Sodium smectites are characterized by dominant sodium in the interlayer boundary, while calcium dominates in calcium smectites. The most common smectite is sodium montmorillonite. Common smectites and their generalized formulas include:

Montmorillonite - $Na_{0.33}(Al_{1.67}Mg_{0.33})Si_4O_{10}(OH)_2,\cdot n\,H_2O$

Beidellite - $Na_{0.36}(Al_{1.46}Fe^{3+}_{0.50}Mg_{0.04})(Si_{3.64}Al_{0.36})O_{10}(OH)_2,\cdot n\,H_2O$

Nontronite - $K_{0.33}(Fe^{3+}_{1.61}Al_{0.39})(Si_{3.67}Al_{0.33})O_{10}(OH)_2,\cdot n\,H_2O$

Stevensite - $Na_{0.16}(Mg_{2.92})Si_4O_{10}(OH)_2,\cdot n\,H_2O$

Saponite - $Na_{0.33}Mg_3(Si_{3.67}Al_{0.33})O_{10}(OH)_2,\cdot n\,H_2O$

Hectorite - $Na_{0.33}(Mg_{2.67}Li_{0.33})Si_4O_{10}(OH)_2,\cdot n\,H_2O$

(Chamley, 1989)

Bentonite deposits originate in situ through the devitrification and alteration of volcanic ash, tuffs and associated rocks ranging in composition from andesite to rhyolite. These reactions occur in an aqueous environment, usually at shallow depth. Bentonite forms in marine or lacustrine environments, in which water chemistry can range from fresh water to alkaline, saline water. Bentonite may also form hydrothermally, where hot or warm spring waters react with near-surface volcanic ash, tuffs or their alteration products. Some bentonite may also form at depth through the long-term action of circulating ground water which alters buried volcanic ash or tuff.

Bentonite is used in many industrial products due to its unique physical and chemical properties. Some of the more important characteristics of bentonite are ion exchange capacity, swelling, absorption, green strength and permeability. These properties arise from the structure of smectite clays. Bentonite swells when water is incorporated into the structure along the interlayer boundaries. The structure expands in response to the added water, creating a viscous gel. Calcium bentonite does not swell as much as sodium bentonite. In general, sodium bentonites are swelling and have sodium as the exchangeable ion, and calcium bentonites are non-swelling and have calcium as the exchangeable ion.

Bentonite is used for a variety of commercial applications in many industries. Sodium bentonite is an important component of well-drilling fluids. It helps keep formational fluids confined, lubricates the drill bit, and keeps cuttings suspended. Bentonite is also used as a liner for landfills and wastewater ponds, and as a binder for foundry molds and iron ore pellets. Bentonite can be heated and expanded to produce light weight aggregate. Calcium bentonite is used for removing impurities from mineral and vegetable oils. Minute particles of dirt, grease and other undesirable materials are adsorbed into the clay structure. Calcium and sodium bentonite also absorb pet wastes (kitty litter) and grease and oils from floors and driveways, much like a sponge. Both types are added to animal feed for trace- element retention and are used to carry pesticides. In addition, specially treated or chemically unique bentonite is used for specialty products such as filtering agents for beer and wine, ingredients in cosmetics, medicines, paint, ink and adhesives, and additions to ceramic and tile mixes to increase flow or add special properties.

In 1989, according to the U.S. Bureau of Mines, California produced 2.4 million tons of clay worth over $36 million (Carrillo, 1990). Bentonite production in California in 1988 was reported at 137,000 tons worth $10 million (Ampian, 1988). Bentonite makes up only 6% of all clay produced by volume, yet accounts for nearly one-third of the value. The majority of bentonite mined is non-swelling calcium bentonite, used mainly for pet waste, oil and grease absorbents and animal feed additives (Ampian, 1988). Most of the swelling bentonite, sodium bentonite and hectorite is used for paint, inks, cosmetics and other specialty materials. Total clay production declined slightly in 1988, although bentonite production and value increased nearly 18% over 1987 (Carrillo and others, 1988; Ampian, 1988).

According to the U.S. Bureau of Mines, about 60% of the fuller's earth produced in the U.S. is montmorillonite and 40% is attapulgite produced in Florida and Georgia (Ampian, 1988). Attapulgite is a clay mineral of the sepiolite group characterized by a linked, chain-like structure, contrasting with the flat, sheet-like structure of smectites. Attapulgite provides important viscosity control in paints, adhesives, and drilling mud, and is also used extensively as an absorbent. Although bentonite mined in California is used in similar applications as montmorillonite and attapulgite mined elsewhere, the U.S. Bureau of Mines does not classify any clay mined in California as fuller's earth.

Demand for bentonite is expected to increase slightly. Increases in bentonite demand in California depend on increased demand for lightweight aggregate, absorbents and pet litter, since the production of specialty clays has been stable. New specialty products could increase production of high-quality bentonite, but would not add significant tonnage to the total output.

Ron Churchill, Associate Geochemist, performed all the DMG X-ray analyses of collected clay samples.

For further information, please call (916) 445-5716, the DMG centralized information number.

PART I : UNITED STATES AND WORLDWIDE

(Data in thousand short tons, unless noted)

1. United States Production and Use :

In 1989, clays were produced in all states except Alaska, Delaware, Hawaii, Rhode Island, Vermont and Wisconsin. The leading 30 firms supplied about one-half of the output, and about 300 firms provided the remainder. Together, these firms operated about 1,100 mines. Estimated value of all marketable clay produced was about $1.2 billion or $200 million below the record high of 1988. Major domestic uses for specific clays were estimated as follows : kaolin - 44% paper, 9% refractories, and 2% rubber ; ball clay - 17% sanitaryware, 11% floor and wall tile, 8% dinnerware and pottery ; fire clay - 55% firebrick, 11% foundry sands; bentonite - 29% drilling mud, 24% foundry sand bond, 14% iron ore pelletizing ; fuller's earth-69% absorbent uses, 9% insecticide dispersant; and common clay- 95% construction materials.

2. Salient Statistics-United States[1]:

	1985	1986	1987	1988	1989[e]
Production, mine:					
Kaolin	7,793	8,549	8,827	9,891	9,400
Ball Clay	902	887	984	1,091	1,100
Fire Clay[2]	974	592	804	875	820
Bentonite	3,195	2,813	2,806	3,165	3,600
Fuller's earth	2,059	1.910	2,057	2,175	2,100
Common clay	30,051	29,869	32,179	31,872	33,200
Total	44,974	44,620	47,657	49,069	50,220
Imports of consumption	41	38	38	36	30
Exports	2,780	2,913	3,332	3,897	4,000
Consumption, apparent	42,235	41,745	44,363	45,208	46,250
Price	per ton depending on type and quality				
Stocks, year end[3]	NA	NA	NA	NA	NA
Employment: [e] Mine	2,000	2,000	2,000	2,000	2,000
Mill	9,400	9,400	9,200	9,300	9,200
Net import reliance[4] as a percent of apparent consumption	Net exporter				

3. Recycling:

Insignificant.

4. Import Sources (1985-88):

Mexico and the United Kingdom, 38% each; Canada, 8%; other, 16%.

5. Tariff

Item	Number	Most Favored Nation (MFN) 1/1/90	Non-MFN 1/1/90
Kaolin and other kaolinitic clays, whether or not calcined[5]	2507.00.00	32.5	$2.46
Bentonite[5]	2508.10.00	39.4	$3.20
Fuller's and decolorizing earths[5]	2508.20.00	24.6	$1.48
Fire clay[5]	2508.30.00	49.2	$1.97
Common blue and other ball clays[5]	2508.40.10	46.7	$1.97
Other clays[5]	2508.40.50	46.7	$1.97
Chamotte or dinas earth[5]	2508.70.00	Free	Free
Activated clays and earths[6]	3802.90.20	2.5%	0.6%+ 30%
Expanded clays and mixtures[6]	6806.20.00	4.9%	30%

[e] Estimated.
[1] Excludes Puerto Rico.
[2] Refractory uses only.
[3] Data on stocks are not available and are assumed to be zero for apparent consumption and net import reliance calculations.
NA Not available
[4] Defined as imports - exports + adjustments for government and industry stock changes.
[5] Per metric ton.
[6] Ad valorem per kilogram.

6. Depletion Allowance:

Kaolin, ball clay, bentonite, fuller's earth, and fire clay, 14% (Domestic), 14% (Foreign); clay used for extraction of alumina or aluminum compounds, 22% (Domestic); clay and shale used for making brick, tile, and light-weight aggregate, 7.5% (Domestic) 7.5% (Foreign); clay used in making drainage and roofing tile, flowerpots, and kindred products, 5% (Domestic), 5% (Foreign).

7. Federal Government Stockpile:

None.

8. Worldwide Events, Trends, and Issues:

Total clays sold or used by domestic producers in 1989 increased 2% in tonnage while decreasing 9% in value. The clay producers operated between 60% to 95% of capacity during the year. The trend of increasing exports, despite a strengthening U.S. dollar, continued and annual growth begun in 1982, except for 1983, by increasing shipments about 3% to 4.0 million tons, surpassing the 1988 export record-high year of 3.9 million. Exports are traditionally limited to the higher priced premium specialty clays. It is estimated that in 1990 domestic mine production of clays will be 49 million tons and that U.S. apparent consumption will be 45 million tons. The continued growth of the energy intensive clay-base industries could be slowed again by the erratic disparity in costs between fuels, such as oil and natural gas, and lower construction rates. Average prices for most clays are expected to rise slowly, reflecting higher quality requirements for the specialty clays and increasing costs associated with land acquisition, land rehabilitation, inflation, and environmental and energy factors. Greater recovery of by-products is anticipated as a result of processing technology improvements that address increasingly acute problems of solid-waste disposal.

Further enhancement of the U.S. position as a major world supplier of high-quality clays is assured by the possession of more than adequate resources of all major types of clay coupled with the clay-processing technology necessary to provide large quantities of consistent quality clays over extended periods.

In 1989, imports of Mexican acid-activated bentonites, unchanged at 12,000 tons from 1988, continue to adversely affect the domestic producers that are concentrated in the gulf coast area.

9. World Mine Production, Reserves, and Reserve Base:

Not Available.

10. World Resources:

Clays are divided for commercial purposes into kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay. Resources of these types of clay are extremely large except for lesser resources of high-grade ball clay and sodium-bentonite. Resources of kaolin in Georgia are estimated to be 5 to 10 billion tons.

11. Substitutes:

Limited substitutes and alternatives, such as talc and whiting, are available for filler and extender applications.

PART II: CALIFORNIA

12. Geological Occurrences

The origin of bentonite deposits in California can be divided into two basic categories: 1) alteration of volcanic ash or tuff in situ, in an aqueous environment, and 2) hydrothermal alteration of volcanic ash or tuff.

In situ alteration of volcanic ash is the most common origin of bentonite worldwide. Alteration may occur in a wide range of sedimentary environments. Bentonite has been found interbedded with coal in marine and estuarian environments, and in fresh water and alkaline lake environments (Grim and Güven, 1978). Glassy volcanic ash readily alters to smectite, due to its chemical instability and permeability. The original composition of the ash is important in determining whether or not smectites will be the alteration product. Formation of smectites requires glassy ash, alkalis, and magnesium (Papke, 1970).

In California, the vast majority of bentonite deposits occur in desert regions of Inyo, Kern, San Bernardino, San Diego and Imperial counties. These deposits are found in Tertiary lacustrine sediments. A few have been hydrothermally altered, most notably the hectorite deposit near Hector, San Bernardino County. Extensive bentonite beds occur in Eocene marine sediments in San Benito County and in Pliocene marine sediments in Imperial County. Smectites are important soil-forming minerals and can be found in a variety of soil environments. Sediments containing sodium montmorillonite weather to a unique, crackly, "popcorn" texture. Expansive soils and dry lake deposits, although not true bentonites, are sometimes used locally, depending on smectite content.

The thickness and extent of bentonite deposits are generally reflective of their mode of origin and depositional environment. Marine bentonites usually have a large areal extent and occur in thick, continuous beds. Bentonite beds of the marine Kreyenhagen shale, for example, crop out for 12 miles along the southwest flank of the Vallecitos syncline in San Benito County. Bentonite beds up to 50 feet thick have been identified by Aune and others (1959). The areal extent and thickness of the bentonite beds suggest rapid deposition of volcanic ash over a considerable area. Lacustrine bentonite

Photo 1. Altered tuff beds of the Ricardo Formation, western El Paso Mountains, Kern County. These tuff beds contain zeolites and calcium montmorillonite. *Photo by Mike Silva.*

deposits found in Tertiary sediments are usually thin and isolated, limited to the extent of the lacustrine environment at the time of deposition (Photo 1). Lacustrine bentonite beds of the Aetna Group, of probable Miocene age, are exposed for a mile and range in thickness from 2 to 12 feet.

Bentonite deposits in Tertiary lakes usually form in a small portion of the lake. Salinity, pH and cation availability of the water determine the products of ash alteration. In alkaline lakes, high pH favors the formation of zeolites from volcanic ash. Zeolites are so common in Tertiary lake deposits that some operators were mining and selling zeolites as non-swelling bentonite. This would indicate that zeolites can substitute for calcium bentonites in certain applications (Vredenburgh, 1990). Most likely, bentonite forms where less alkaline water enters the lake from surface or underground springs or streams, lowering the pH and salinity enough so that smectite is formed.

Hydrothermal bentonite deposits are characterized by irregular size and shape and unique mineralogy (Photo 2). Hectorite deposits near Hector, San Bernardino County, were formed through the alteration of volcanic glass and tuff deposited in an alkaline lake. Hot springs containing lithium and fluorine combined with magnesium in the lake water to alter glassy volcanic material to hectorite. Where hot spring activity was absent, volcanic ash has been altered to zeolites. Post-depositional faulting and slumping of altered material contribute to the podiform structure of the hectorite deposits. In one deposit located in the Coso Formation, fault-controlled hot or warm spring waters altered an existing bentonite. The alteration product has been identified tentatively by DMG as a mixed-layer smectite-kaolin.

13. Localities

Colusa County

Antelope Valley deposit: A deposit of brown, impure bentonite is located 11 miles west of Williams in section 18, T15N, R4W, MDBM, north of Antelope Creek and State Highway 20. The clay is brown, blocky and weathers to a crumbly popcorn texture. The clay is exposed along the flanks of a north-trending ridge in Pliocene sediments of the Tehama Formation. Analysis by DMG indicates the clay is composed of montmorillonite, zeolite and quartz. This deposit has not been prospected and was described by J.L. Post of California State University, Sacramento (personal communication, 1990).

Photo 2. Close-up of freshly exposed hectorite. The clay is white, waxy, with a high moisture content, and contains up to 50% carbonate. *Photo by John Clinkenbeard.*

San Benito County

Vallecitos bentonite/ Ashurst-Lewis Pit: Three distinct bentonite beds crop out along a westerly-trending belt stretching 2 to 13 miles northwest of New Idria, San Benito County (generally the north half of T17N, R11E and southeast portion of T16S, R10E). The beds are exposed for at least 10 miles just south of the Panoche-Idria Highway between McDonald Ranch and Ashurst Ranch, and occur in four stratigraphic horizons in the Eocene Kreyenhagen shale. The bentonite is gray, white-weathering and occurs in massive outcrops subject to landslides.

The thickest, most widespread bed is near the base of the formation, and thickness varies from 60 to 120 feet. Above this bed are at least two horizons of discontinuous beds or lenses. These are thin and impure and considered noncommercial. The uppermost bentonite bed is fairly pure and lies near the contact of the Kreyenhagen and Temblor formations. Up to 60 feet thick, this unit may have been removed by erosion in some areas. These bentonite beds consist of swelling sodium montmorillonite derived by alteration of volcanic ash in a quiet, marine environment (Aune and others, 1959).

The Wilbur-Ellis Company of Fresno has been mining bentonite from this area since 1959. Their pit is located in section 17, T17S, R11E, MDBM. The mined material is used as a binder for pelletizing hay and feed cubes, as a sealant for reservoir liners, and as an extender (Vredenburgh, 1990).

D.Z. Stewart prospect: A fuller's earth deposit on the D.Z. Stewart property was reported in section 30, T15S, R7E, MDBM, about 10 miles south of Paicines. A second deposit was reported in section 33. The bentonite is derived from Miocene volcanic material and was worked in the late 1930's. This location has not been verified (Averill, 1947).

Monterey County

Jens: 1,250 tons of fuller's earth were reportedly produced from 1914-1920. The material was used for fulling wool and clarifying mineral oils. The deposit has not been located and is not described in the literature (Hart, 1966).

Fresno County

Unnamed: Holdings of claims for fuller's earth were reported in sections 20, 28 and 30, T21S, R17E, MDBM, about 12 miles southeast of Coalinga in Fresno County. These deposits are located in the Plio-Pleistocene Tulare Formation, consisting of thin-bedded, fine-grained lake sediments. The clay bed is up to 18 feet thick and is an altered volcanic ash. These locations have not been verified (Bradley, 1914; Vredenburgh, 1990).

Kings County

C.E. Boyd prospect: Small production of fuller's earth and gypsum was reported in 1913 in section 13, T24S, R17E, in the edge of the Kreyenhagen Hills northwest of Dudley. This location has not been verified (Bradley, 1914).

Webb and Mingus: Deposits of gray fuller's earth were reported in the northeastern portion of the Kettleman Hills in section 26, T21S, R17E, MDBM. This location has not been verified (Franke, 1930).

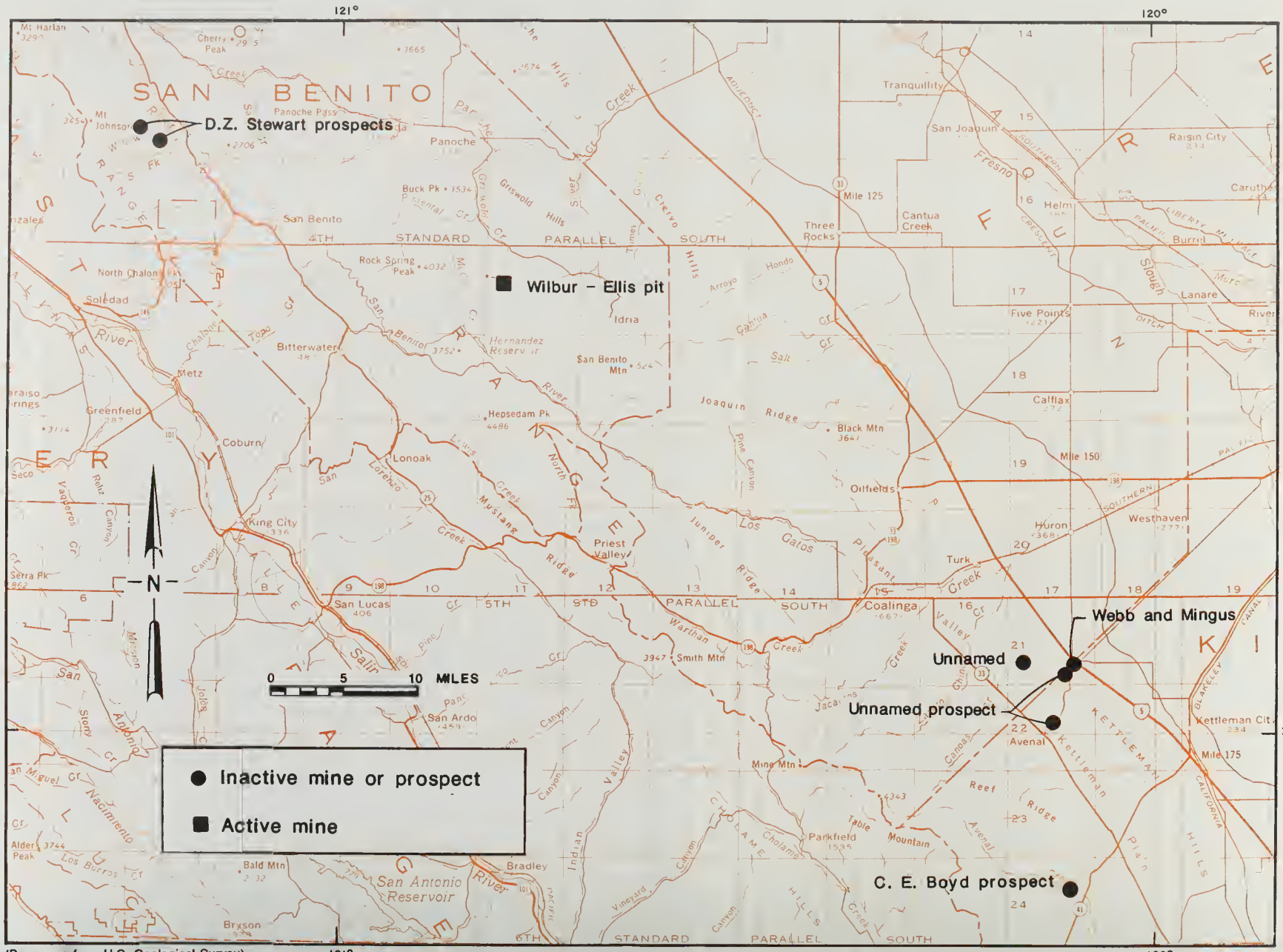
Unnamed: Two prospects are reported in the Plio-Pleistocene Tulare Formation on the north line of section 35, T21S, R17E, MDBM and in section 15, T22S, R17E, MDBM where Highway 269 crosses the clay bed. The clay bed is 18 feet thick and is an altered volcanic ash. The clay does not meet specifications as a natural fuller's earth, but can be activated with acid. These locations have not been verified (Vredenburgh, 1990).

Inyo County

Centennial Flat pit: Southern Sierra Mining mines a calcium magnesian montmorillonite from the Plio-Pleistocene Coso Formation on the west side of Lower Centennial Flat. The pit is located in the center of section 6, T19S, R39E, MDBM, about 6 miles southeast of Owens Lake, south of Highway 190. The clay is a white, massive calcium montmorillonite and is interbedded locally with tuff. Maximum thickness is unknown, but is at least 40 feet. X-ray analysis by DMG reveals the clay is composed of montmorillonite, quartz and calcite. The clay formed through alteration of volcanic ash in a lacustrine environment. Mined clay is ground and air dried and used as a binder for alfalfa cubes shipped to Japan (DMG Mineral Property Report Files).

Vermillion Canyon pit: Southern Sierra Mining operates a second clay mine in Vermillion Canyon, about 6 miles southeast of Dirty Socks Hot Springs. There are two small pits located in the NE4, NW4 of section 24, T19S, R37E, MDBM with clay exposed in eight claims owned by the company. The clay is a calcium, iron-rich montmorillonite from the Plio-Pleistocene Coso Formation; it is light brown to off-white in color and locally iron-stained. Maximum thickness is 75 feet (confirmed by drilling). Formed through the alteration of volcanic ash in a lacustrine environment, the clay is ground, air dried and used as a carrier for insecticides. The clay has also been tested for ceramics, but has not been used for that purpose (DMG Mineral Property Report Files).

Black Springs pit: The Black Springs Clay Company produces clay from a pit in the Plio-Pleistocene Coso Formation located 1.5 miles north of Black Springs in southwestern Lower Centennial Flat. The pit is located in the S2 of section 15 and the N2 of section 22, T19S, R39E, MDBM. There are other prospect pits north and west of this location. The clay is a light-colored calcium montmorillonite with local manganese staining and is associated with calcite. X-ray analysis conducted by DMG indicates the material is composed of montmorillonite, calcite and quartz. Similar to other bentonitic deposits in the Coso Formation, the clay was formed in a lacustrine environment from volcanic ash or tuff. Small amounts of clay are used by U.S. Tile for roofing tile (DMG Mineral Property Report Files).



(Base map from U.S. Geological Survey)

Figure 2. Bentonite mines and prospects in San Benito, Fresno and Kings counties.

Sidehill mine: The R.T. Vanderbilt Company operates the Sidehill mine, located in the NW4 of section 19, T26N, R5E, SBBM, about 6 miles northwest of Death Valley Junction. The pit is located in the Pliocene Furnace Creek Formation. The clay, a high-quality sodium montmorillonite, is mined from two beds, as much as 20 feet thick, that strike N10°-30°E and dip 40°SE. The clay beds are underlain by calcium carbonate beds and volcanic ash and most likely formed in a lacustrine environment from volcanic ash or tuff. Mined material is used in pharmaceutical products and cosmetics, and commands a high price (Taylor, 1986; McAllister, 1970).

IMV mine: Industrial Minerals Ventures operates a hectorite/saponite mine immediately west of Franklin Well, on the west side of the Armagosa River in the NE4, SE4 of section 6, T26N, R5E, SBBM. The deposit occurs in Quaternary lake sediments, and in cross section resembles a flattened cigar shape with a northwest trend and abrupt lateral termination. The clay is white, waxy and swells in water. The hectorite is cemented with calcite and was formed from the alteration of water-lain volcanic sediments by calcium-rich hot springs in a lacustrine environment. The clay is used as a specialty drilling mud and as a flow controller in construction materials (Taylor, 1986).

Armagosite mine: Bentonite deposits occur immediately west of Shoshone, tentatively located in the NW4 of section 31, T22N, R7E, SBBM. The bed crops out a few feet above the valley floor in the face of a terrace of sediments deposited by Pleistocene Lake Tecopa. Thickness varies from 1 to 10 feet. The bentonite is white, smooth, soft, friable and somewhat sticky. Alteration of ash by warm springs formed the bentonite. Mining started in 1920 and continued for years. The deposit is worked out. Attempts by DMG staff to locate the bentonite have been unsuccessful. The material was used in oil refining and by the local Indians as a natural soap and shampoo. Chemical analysis published by Melhase (1926) reveals a high sodium content, somewhat anomalous with the clay's natural fuller's earth properties (Melhase, 1926; Sheppard and Gude, 1968).

Calearth mine: The Calearth mine, also known as the Sierra Talc Mine, is located in the projected SW4 of section 23, T18S, R38E, MDBM, on the northeast flank of the Coso Range, about 11 miles northeast of Olancha, southeast of Owens Lake. The clay, a naturally active fuller's earth, is a calcium montmorillonite and occurs within the Plio-Pleistocene Coso Formation. The bentonite averages 16 feet in thickness, strikes N70° to 85°E and dips 10°N. Basalt flows overlie the deposit that most likely formed in a lacustrine environment from volcanic ash or tuff. Fault-controlled hydrothermal solutions have subsequently altered the bentonite. X-ray analysis by DMG has tentatively identified the clay as a mixed-layer smectite-kaolinite. The clay is unusual in that it is both a naturally active fuller's earth and acid activatable. Most of the clay was used for filtration and decolorization of animal, vegetable and petroleum oils. The deposit was mined from the late 1940's until the late 1950's, primarily by underground methods (Lamar, 1953; Norman and Stewart, 1951; Stinson, 1977; Taylor, 1986).

Ibex Bentonite mine: The Ibex bentonite mine is operated by BFM Associates (previously operated by Pfizer, Inc.) and is located in the projected NW4 of section 2, T20N, R6E, SBBM, about 5 miles north of Ibex Pass, 8.5 miles south of Shoshone, one- half mile west of the junction of Highway 127 and the Eclipse turnoff. A 10- to 12-foot-thick bed of green bentonite occurs in lake deposits of Pleistocene Lake Tecopa, capped by a zeolite-rich altered tuff, a few inches to a few feet thick. The Ibex bentonite is remarkably pure and free from detrital impurities that are feldspar, quartz, biotite and a variety of lithic fragments. In general, Lake Tecopa deposits consist of gray, brown to green smectite-bearing mudstones, siltstones and sandstones. Sepiolite is also found in some claystones. Sheppard and Gude (1968) suggest a detrital origin for clay minerals in Lake Tecopa. The purity of the Ibex bentonite and low detrital component suggest in situ alteration of volcanic ash in an alkaline lake. Clay has been mined for years at this site, first by Pfizer and now by the current company. Principal uses are asphalt sealers (to prevent loss of moisture), well drilling mud and, perhaps the most unusual use for bentonite in California, clay for mud baths. Tens of thousands of tons of clay have been mined from this site (DMG Mineral Property Report Files).

Funeral Mountains prospects: A number of bentonitic clay prospects are located about 4 miles east of Pyramid Peak, on the east side of the Funeral Mountains. These prospects are thin, low-grade and discontinuous and contain various amounts of montmorillonite, zeolite, opal and calcite. All prospects are located in lakebed sediments and ash-fall deposits of the Miocene Horse Spring Formation. The bentonitic beds vary in thickness from 2 to as much as 8 feet, but average 4 feet. Clay was formed by in situ alteration of silicic ash in a fresh water lake. The prospects are: the Bentonite Placer prospect, located in the SW4 of section 17; the Yellow Heart prospect, located in the SE4 of section 18; the Kaolin Extension prospect, located in the SE4 of section 10; the Kingfish No. 1 prospect, located in the NW4 of section 14; and the Kingfish No. 2, located in the SW4 of section 14, all in T26N, R4E, SBBM (Neumann, 1984; Taylor, 1986).

Deborah prospect: The Deborah prospect is located in the NE4, section 16, T26N, R4E, SBBM, on the east side of the Funeral Mountains, about 4 miles east of Pyramid Peak. The gray-green bentonite occurs within the Miocene Horse Springs Formation and is exposed in a 3.6-acre basin. Thickness averages 2 feet. Samples taken by the U.S. Bureau of Mines contained montmorillonite, cristobalite and gypsum. The clay was formed by in situ alteration of ash in a fresh water lake. Three samples taken met industry standards for use as a foundry sand bonding clay. Workings include five trenches and three small prospect pits (Neumann, 1984).

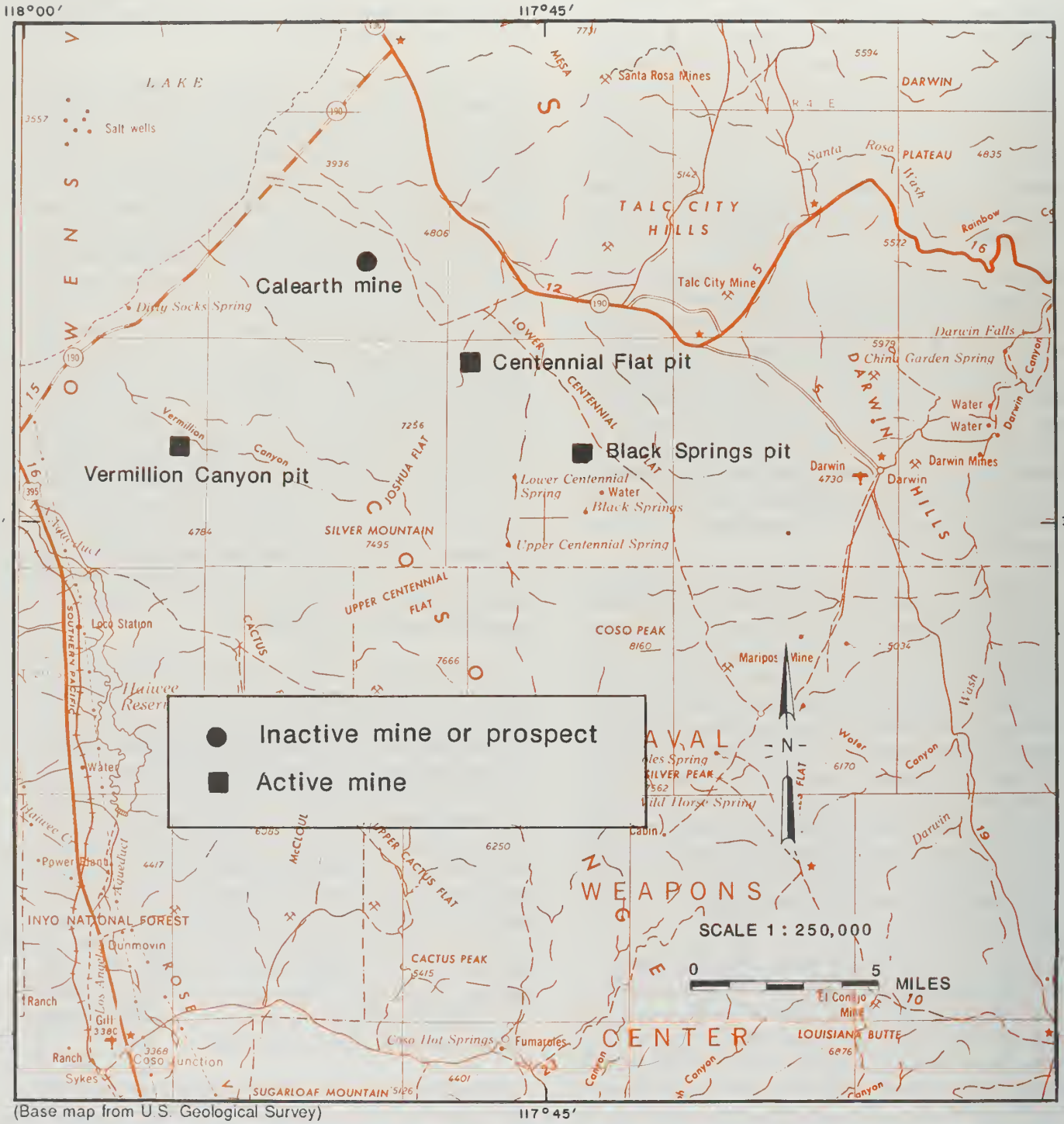


Figure 3. Bentonite mines in southwestern Inyo County. Scale 1:250,000.

Kaolin mine prospect : The Kaolin mine prospect is located in the NE4 of section 15, T26N, R4E, SBBM on the east side of the Funeral Mountains, about 5 miles east of Pyramid Peak, 1 mile east of the Deborah prospect. Bentonitic clay, seen only on the mine dump, displays popcorn texture on the surface and occurs within the Miocene Horse Spring Formation. Samples taken by the U.S. Bureau of Mines contain calcium montmorillonite. The clay was formed by in situ alteration of ash in a fresh water lake. The clay is suitable for use as a pelletizing agent and as a bonding medium. Workings consist of a collapsed shaft (Neumann, 1984).

Ballarat saponite prospect : Saponite occurs in dolomitic limestone about 3 miles northeast of Ballarat, in the SW4 of section 26, T21S, R44E, MDBM, on the west flank of the Panamint Range. Saponite is a magnesium smectite with physical properties similar to montmorillonite. The clay occurs in joints and open fractures in the late Cambrian Noonday Dolomite Formation. Clay seams occur chiefly in bedding joint planes and tend to be lenticular and not more than 1 foot thick. Saponite content ranges from 55% to 70%, with tremolite, diopside and lesser amounts of calcite, quartz, feldspar and talc. The clay was formed by hydrothermal alteration of limestone and dolomite. Representative quantities of this clay have been added to the Source Clay Repository of the Clay Minerals Society. Tests indicate the clay is suitable for drilling mud. Workings consist of a small prospect pit (Post, 1984).

Kern County

Snow White mine: Engelhard Minerals and Chemical Corporation controls the Snow White mine located in the NE4 of section 30, T29S, R38E, MDBM, 1 mile west of Last Chance Canyon on the north side of the El Paso Mountains, 3 miles east of Ricardo. Last mined in 1987, the white clay occurs in Member 2 of the Pliocene Ricardo Formation, a white tuff (Photo 3). The bentonite bed, up to 20 feet thick, strikes N30°E, dips 20°W and is capped by a basalt flow. Analyses by Engelhard Minerals and DMG reveal the clay is 70 to 90% calcium montmorillonite with opal and zeolite and has a high brightness, which is unusual for a montmorillonite. Tuff beds of Member 4 of the Ricardo Formation have been altered after tilting by circulating subsurface water. This is probably the mechanism for alteration at the Snow White mine. The clay

Photo 3. Calcium bentonite at Snow White mine, Kern County. This altered tuff contains up to 90% calcium montmorillonite. Note extreme whiteness of clay and sharp alteration boundary. *Photo by Dan Eyde.*

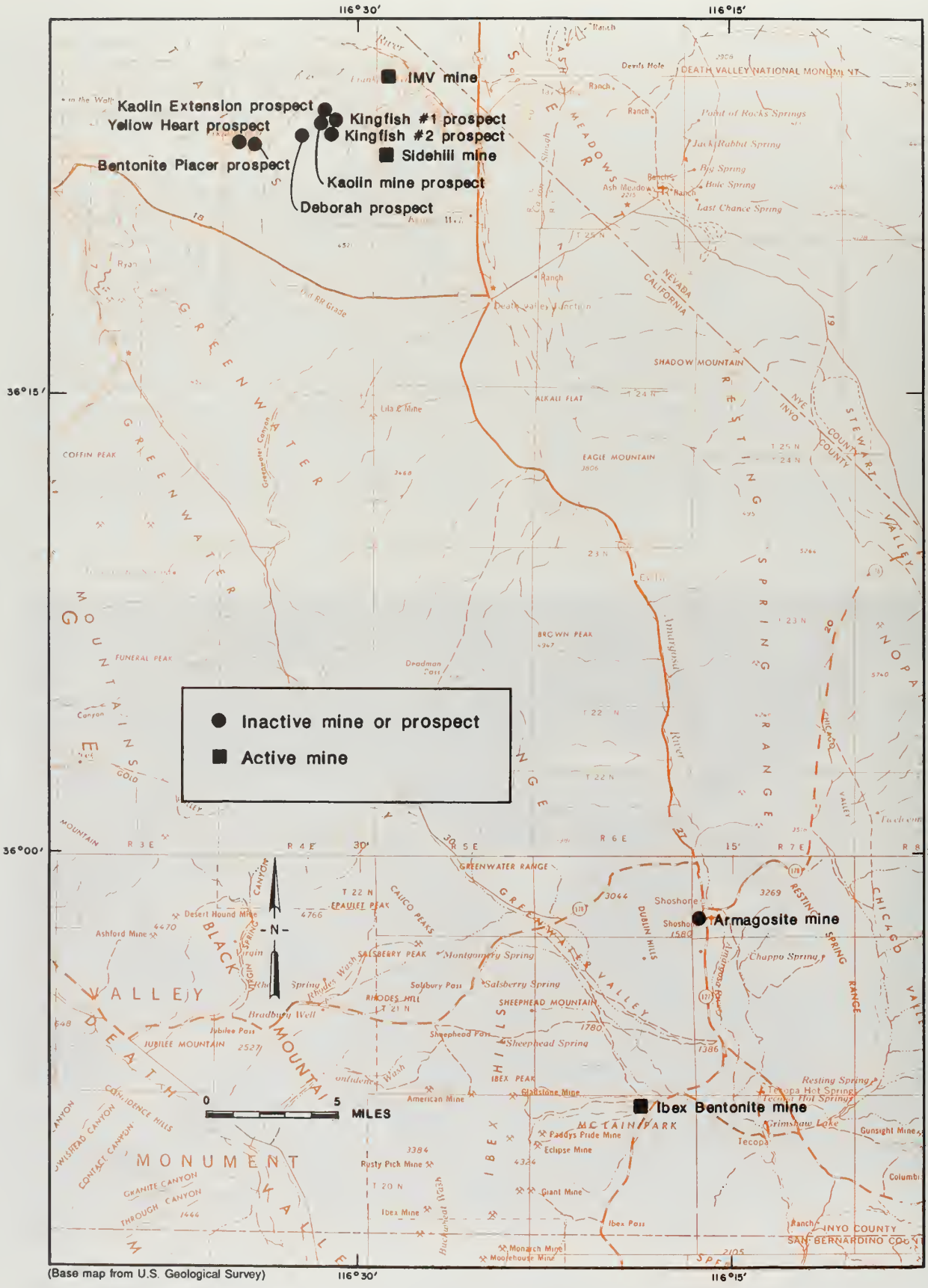


Figure 4. Bentonite mines and prospects in southeastern Inyo County.

has been used for oil refining, paper coating and carbonless copy paper. Workings consist of two large open pits. The company estimates reserves at 1.2 million tons (Dibblee, 1952; Sheppard and Gude, 1965; DMG Mineral Property Report Files).

Hancock mine: The Hancock mine is located in the NW4 of section 30, T29S, R38E, MDBM, 2 miles southwest of Holloway Camp on the north side of the El Paso Mountains, 2.5 miles east of Ricardo. Hard, creamy white clay occurs in Member 2 of the Pliocene Ricardo Formation, a white tuff. Strike and dip are roughly N30°W, 20°W. X-ray analysis by DMG indicates the clay contains montmorillonite and zeolites. Tuff beds of Member 4 of the Ricardo Formation have been altered after tilting by circulating subsurface water. This is probably the mechanism for alteration at the Hancock mine. Workings include a large hillside cut that has been disturbed recently, and at least two other small test pits. The clay was used for filtering petroleum products and as a filler in rubber manufacturing (Dibblee, 1952; Sheppard and Gude, 1965; DMG Mineral Property Report Files).

Iron Canyon mine: The Iron Canyon mine, also known as the Brown-White, is located in the SE4 of section 25, T29S, R37E, MDBM, on the north side of the El Paso Mountains, 2 miles east of Ricardo. Hard, creamy, white clay occurs in Member 2 of the Pliocene Ricardo Formation, a white tuff. Strike and dip are roughly N30°W, 20°W. X-ray analysis by DMG indicates the clay contains montmorillonite, zeolites and quartz. Tuff beds of Member 4 of the Ricardo Formation have been altered after tilting by circulating, subsurface water. This is probably the mechanism for alteration at the Iron Canyon mine. The only workings consist of an adit of undetermined length above the creekbed. Production was several thousand tons. The clay was used for filtering petroleum products and as a filler in rubber manufacturing (Dibblee, 1952; Sheppard and Gude, 1965; DMG Mineral Property Report Files).

White Clay prospects: The White Clay prospects are located in the NE4 of section 30 and the NW4 of section 29, T29S, R38E, MDBM, on the southwest slope of a ridge 3 miles west of Highway 14 and 3.5 miles north of Gypsite. Both deposits occur in Member 2 of the Pliocene Ricardo Formation. Alteration of the tuff is incomplete in the northern prospect and limited in the southern prospect. Bedding trends N30°E and dips 20°W. X-ray analysis by DMG indicates the clay is composed of montmorillonite and zeolites. Tuff beds of Member 4 of the Ricardo Formation have been altered after tilting by circulating subsurface water. This is the probable mechanism for alteration at the White Clay prospects. The northern prospect has only been sampled, while a small, 20-foot-long adit exists at the southern prospect (Dibblee, 1952; Sheppard and Gude, 1965; DMG Mineral Property Report Files).

Stevens prospect: The Stevens prospect is reported in the SE4 of section 17, T29S, R38E, MDBM, 1 mile west of Cuhady Camp on the south slope of Red Buttes. This location is mapped as Pliocene Ricardo Formation by Dibblee (1952). White to pale gray bedded lithic tuff is altered partially to bentonite. The deposit has been developed by three short adits. This location has not been verified (Troxel and Morton, 1962).

Koehn prospect: The Koehn prospect, also known as the Red Rose and White Rose claims, is reported in the SW4 of section 20, T29S, R38E, MDBM, just south of Cuhady Camp in Last Chance Canyon. Alternating layers of white swelling and non-swelling bentonite occur on the steep western slope of Last Chance Canyon. The clay occurs in Member 2 of the Pliocene Ricardo Formation and is overlain by pale, greenish-gray shaly tuff and basalt. Beds strike N40°E and dip 19°NW. The deposit is developed by two adits, one 35 feet long and one 20 feet long. This location has not been verified (Troxel and Morton, 1962).

California Fuller's Earth: The California Fuller's Earth deposit is located in the SW4 of section 14, T27S, R28E, MDBM, in Granite Canyon, about 1 mile northeast of Knob Hill. The deposit consists of pale buff, silty tuffaceous sandstone that contains thin pebbly partings of quartzite, granite and dark metamorphic rocks in the Miocene Round Mountain silt. The clay bed is flat-lying and exposed over a wide area. The Round Mountain silt consists of fine-grained diatomaceous marine sandstone with interbeds of siltstone and claystone. There is no evidence of volcanic material. Diatoms may contribute to the filtering property of the clay. First mined in 1898, material was mined in the 1910s by California Fuller's Earth from two open pits and used as an adsorbent in refining animal and vegetable oils (Troxel and Morton, 1962; Vredenburgh, 1990).

Aetna group: The Aetna group of bentonite prospects is located in the NW4 of section 16, T28S, R40E, MDBM, 1 mile west of Highway 395, 9 miles south of Ridgecrest. Nearly flat-lying bentonite beds 2 to 12 feet thick are intercalated with arkosic sandstone and tuff, overlain by dark volcanic rocks and exposed for about a mile. The clay is pink to white, swells slightly and is relatively pure. Clay occurs in Tertiary nonmarine sediments of possible Miocene age. X-ray analysis by DMG reveals the clay contains calcium montmorillonite and quartz. The clay was formed by in situ alteration of volcanic ash in an aqueous environment. Clay was mined from two small pits and is exposed in numerous cuts and pits in sections 16 and 17. Claims at one time totalled 1,100 acres (Troxel and Morton, 1962).

Bentonite Knoll prospects: Also known as Unnamed clay deposit #1, bentonite is reported in the NW4 of section 7, T28S, R40E, MDBM and the SE4 of section 1 and the NE4 of section 12, T28S, R39E, MDBM, about 7 miles southwest of Ridgecrest on the north flank of the El Paso Mountains. Pale pink and white swelling bentonite occurs in a gray to white, fine- to coarse-grained tuff several tens of feet thick. The tuff is underlain by metavolcanic rocks and overlain by black vesicular basalt. Tuff beds strike S75°W and dip 10°S. Development consists of three shallow trenches. Attempts to locate this prospect by DMG staff were unsuccessful (Troxel and Morton, 1962).

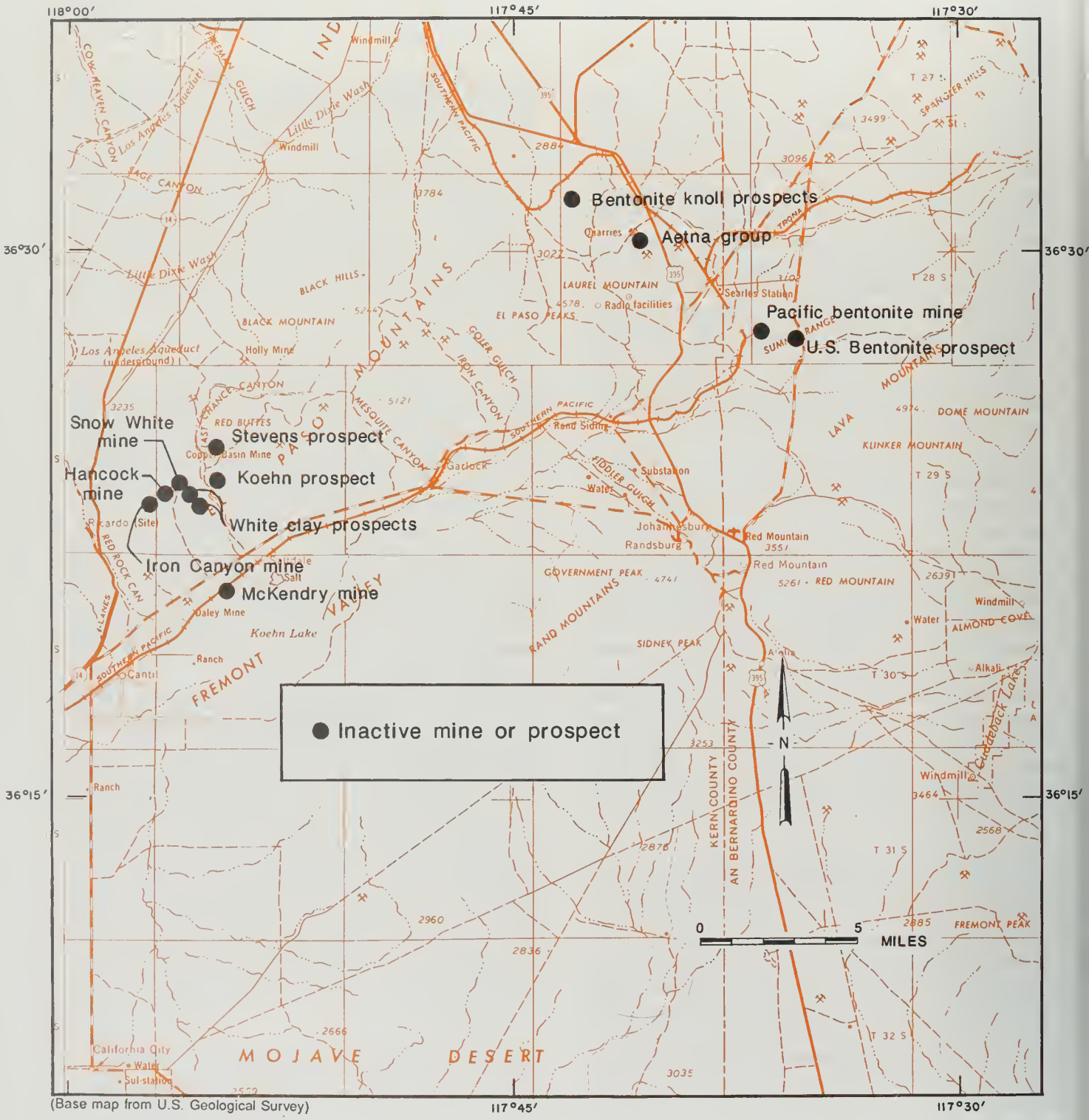


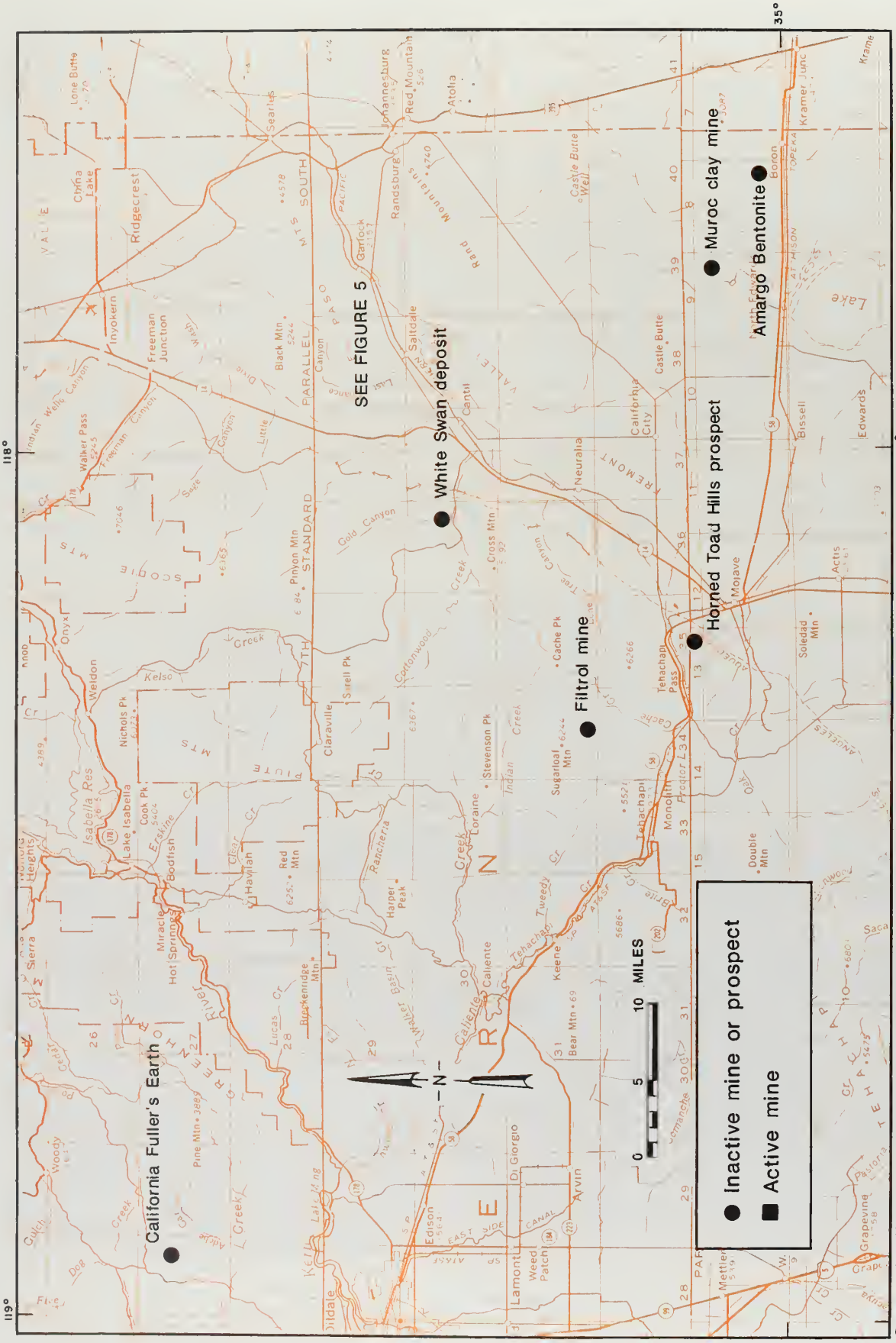
Figure 5. Bentonite mines and prospects in northeastern Kern County and northwestern San Bernardino County.

Amargo bentonite: The Amargo bentonite prospect, also known as the Vanuray claim, is located in the NE4 of section 26, T11N, R8W, SBBM, about 3 miles northwest of Boron, one-half mile south of the U.S. Borax Boron pit. The deposit is now covered by tailings from the U.S. Borax operation. A 20-foot-thick bed of swelling bentonite occurs in steeply-dipping rocks of the Mio-Pliocene lower Tropico group, striking N30°E and dipping 55°NW. The clay is greenish-gray, sandy, with carnotite, opal, iron, and manganese oxides and formed by in situ alteration of rhyolitic ash and tuff in a lacustrine environment. The deposit was mined in the 1940s and 1950s by open pit (Troxel and Morton, 1962).

Muroc clay mine: Bentonite underlies a small hill located in the SE4 of section 3 and the SW4 of section 2, T11N, R9W, SBBM, about 4.5 miles northeast of the city of North Edwards, west of Clay Mine Road. Clay is exposed on the west, east and north sides of a low hill, as a single layer in a series of lacustrine sediments, capped by basalt (Photo 4). The series is part of the Mio-Pliocene lower Tropico group and dips gently to the west. The clay is non-swelling, nearly pure white, and breaks with a hackly fracture. X-ray analysis by DMG reveals the clay is composed of calcium montmorillonite, zeolite and opal. Clay was formed by in situ alteration of volcanic ash in a lacustrine environment. Mined from 1928 to 1945, the clay is naturally active and activatable, classified as a fuller's earth and was used as an adsorbent in petroleum oil refining. Workings consist of several caved adits and small open cuts. Some clay was sold out of state to Texas and Oklahoma. Total production is estimated to be about 40,000 tons (Troxel and Morton, 1962; DMG Mineral Property Report Files).

Horned Toad Hills prospect: Bentonitic beds occur in sediments of the Pliocene Horned Toad Formation located in the NW4 of section 36, T12N, R13W, SBBM, about 4 miles northwest of Mojave. The greenish-gray to brown bentonite, 30 feet thick, crops out on the south flank of a low range of hills and is underlain by white tuffaceous sandstone (Photo 5). The clay bed strikes N55°E and dips 26°NW. X-ray analysis by DMG reveals the clay contains a mixture of montmorillonite, zeolite, quartz and illite. The clay exhibits a crackly, popcorn texture on the surface and was formed by in situ alteration of volcanic ash or tuff in a lacustrine environment. Two small prospect pits were observed (Troxel and Morton, 1962; DMG Mineral Property Report Files).

Photo 4. View of east side of Muroc clay mine. *Photo by Dan Eyde.*



(Base map from U.S. Geological Survey)

Figure 6. Bentonite mines and prospects in southern Kern County.

Photo 5. Bentonite beds exposed in the Horned Toad Hills, northwest of Mojave, Kern County. Crumbly, weathered bentonite is exposed on hills on left. *Photo by Mike Silva.*

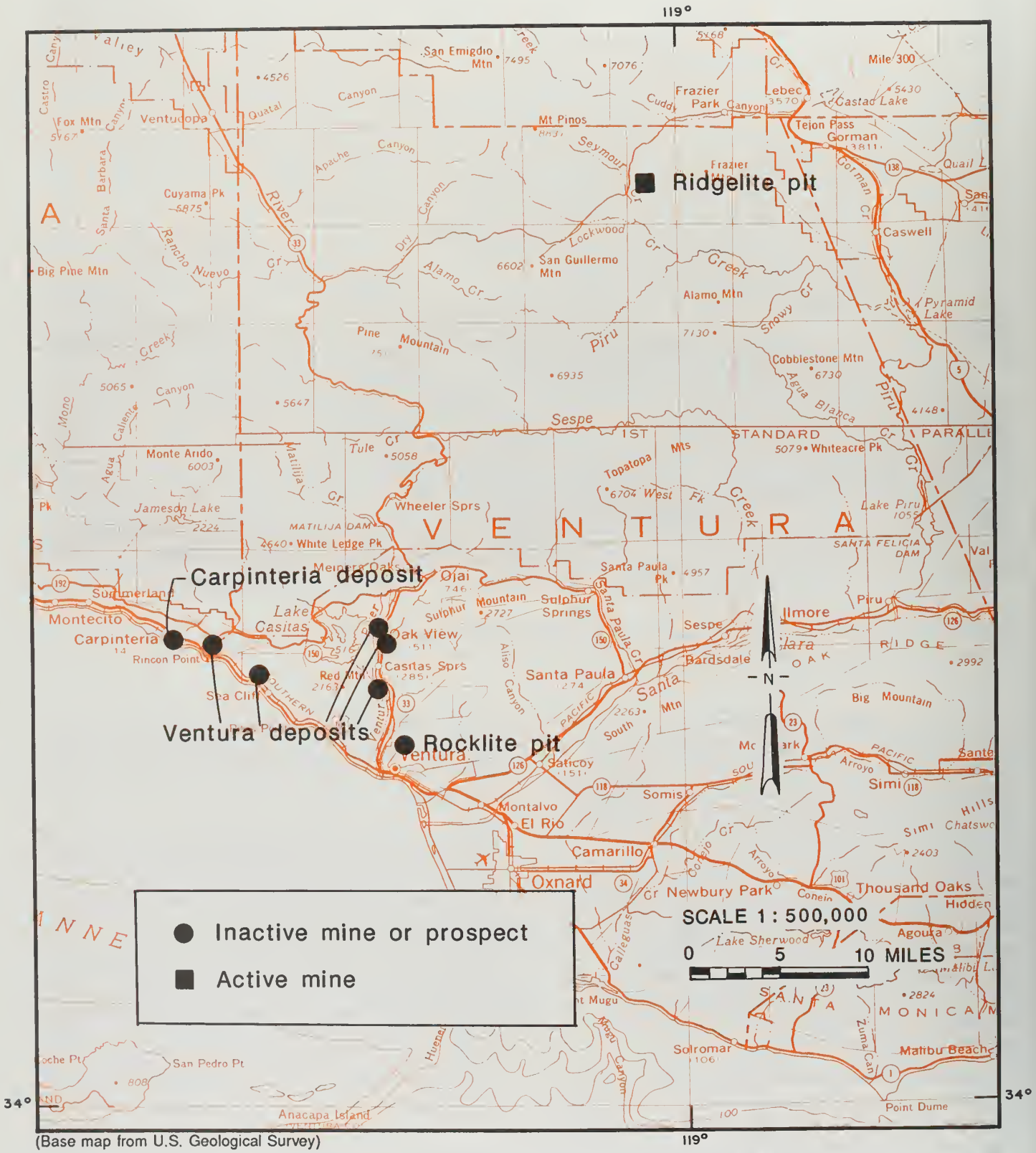
Filtrol mine: The Filtrol bentonite mine is located in the NW4 of section 34, T31S, R34E, MDBM, about 5 miles northeast of Tehachapi, and 2 miles southeast of Sugarloaf Mountain. White to light grayish-white clay occurs at the base of the Miocene Kinnick Formation, overlain by shaly tuff, tuff and an andesite flow, and crops out for several hundred feet. These beds dip gently southwest and strike about N50°W. The bentonite is a non-swelling, high magnesium montmorillonite with minor zeolite sanidine and hornblende. It is naturally active, but not activatable. The clay was formed in situ by alteration of volcanic ash in an aqueous environment. Mining began in 1927 and continued until 1936. The clay was used as a bleaching agent in petroleum refining. Total production is unknown (Troxel and Morton, 1962; Kerr and Cameron, 1936).

White Swan prospect: The White Swan prospect is located in the NE4 of section 14, T30S, R36E, MDBM, about 5 miles northeast of Cinco, one-half mile north of Blue Point. Pale gray to pale green bentonite, up to 10 feet thick, intercalated with pink, green, and gray tuffs, crops out for several hundred yards. This sequence is part of the Miocene Kinnick Formation and strikes N40°E and dips 49°NW. X-ray analysis by DMG reveals the clay contains montmorillonite and zeolites. The clay was formed in situ by alteration of volcanic tuff in an aqueous environment. Two small prospect pits were observed (Troxel and Morton, 1962; DMG Mineral Property Report Files).

McKendry mine: The McKendry bentonite mine is located in the NE4 of section 8, T30S, R38E, MDBM, about 1 mile northeast of Gypsite siding, along the railroad tracks. Greenish-gray, plastic bentonite is exposed in an open pit in Quaternary lakebed sediments of Koehn Dry Lake. The clay swells slightly and is contaminated with salts. X-ray analysis by DMG indicates the clay is composed of montmorillonite, halite, quartz, calcite, zeolite and plagioclase feldspar. The clay was formed in situ by alteration of volcanic material in an alkaline lake. The deposit is developed by a 600-foot-wide, shallow open pit. About 200 tons of clay were produced in 1928 to 1929. The clay was used for tile and drilling mud, but proved unsatisfactory for the latter (Troxel and Morton, 1962; DMG Mineral Property Report Files).

Santa Barbara County

Carpinteria deposit: A deposit of montmorillonite is reported 1 mile south of Carpinteria in the Carpinteria Clay Products pit. The bed is 8 feet thick, strikes east-west and dips



(Base map from U.S. Geological Survey)

Figure 7. Bentonite mines and prospects in Ventura and Santa Barbara counties. Scale 1:500,000.

75°S. The clay is white, brown, and red and contains a large amount of combined water. A 300-foot tunnel was driven into the deposit and considerable tonnage was shipped to Los Angeles for use in oil refining. This location has not been verified (Tucker, 1925).

Ventura County

Ridgelite pit: Pacific Lightweight Products Company operates the Ridgelite mine located in the center of section 19, T8N, R20W, about 3 miles west of Frazier Mountain in northeastern Ventura County. Clay is mined from the Lockwood Clay of Pliocene age that is exposed throughout Lockwood Valley. The maximum thickness of the formation is 275 feet, while thickness of the clay varies from 75 to 150 feet. The clay is tan to gray, weathers brown and fires brownish red. Local exposures of purer white montmorillonite have been observed. Minerals include montmorillonite, with minor quartz, feldspar and mica. The clay was formed by in situ alteration of volcanic ash in an aqueous environment. Mined material is fired in a kiln and used for light-weight aggregate for construction. The deposit has been mined for at least 40 years (DMG Mineral Property Report Files; Carman, 1964).

Ventura deposits: Deposits of bentonitic clay are reported by Kerr (1931). These deposits, five in all, are tentatively located as follows: sections 8 and 9, T3N, R23W, SBBM, 1 mile south of Casitas Springs, west of the Ventura River; directly west and south of Oakview, east of the Ventura River (two deposits); sections 4 and 5, T3N, R24W, SBBM, one-half mile east of Rincon Mountain on Los Sauces Creek; and in section 34, T4N, R25W, SBBM, 1 mile north of Rincon Point, west of Rincon Creek. Described as occurring at the contact of the Miocene Modelo and Rincon formations, the clay is soft, light olive green and swells slightly. Bentonite is interbedded with volcanic ash and argillaceous shale. The clay is composed of montmorillonite with minor zeolite and unaltered ash. Fossil diatoms and foraminifera are also present. The clay was formed in situ by alteration of volcanic ash in a marine environment.

Two mines mentioned in the 28th Report of the State Mineralogist (Tucker and Sampson, 1932) may have mined material from this formation. One is the Associated Oil Company clay pit, a large operation located about 2 miles north of Ventura and 2 miles east of Ventura Avenue. The clay was used for drilling mud and capacity of the plant was 15,000 barrels of mud a day. The other is the Connett pit located 4 miles north of Ventura on Ventura Avenue. This material was also used for drilling mud and was produced from a pit 100 feet by 50 feet by 40 feet deep.

Rocklite quarry : The Rocklite quarry is located in the NW4 of section 33, T3N, R23W, SBBM, about 1.5 miles north of Ventura, one-half mile east of North Ventura Avenue, east of the Ventura River. Bentonitic shale occurs within the lower part of the upper Pliocene to lower Pleistocene Santa Barbara Formation, near the contact with the Pliocene Pico Formation. The material is a blue-gray lamellar, marine clay shale, with sandstone partings. Local concentrations of montmorillonite contribute to landslides in the area. The bentonite was formed by alteration of volcanic material in a marine environment. Pacific Lightweight Products Company operated this mine from 1947 to the mid 1980s. The main product was expanded light-weight aggregate. Hundreds of thousands of tons of clay were mined from this pit. In addition, clay mined near this pit was used for bricks and well-drilling mud (Weber and others, 1973; Lenhart, 1950).

San Bernardino County

Barber Bentonite: The Barber bentonite is reported to be located on what is now Fort Irwin, 18 miles north of Harvard, in the vicinity of Bitter Springs. Discovered at the turn of the century, the clay beds are at least 30 feet thick and occur in lakebed sediments of the Miocene Barstow Formation (Photo 6). White bentonite up to 100 feet thick is reportedly exposed for 3,000 feet. The bentonite is overlain by a vesicular basalt flow. Old photographs show the clay as white and it appears relatively pure. The clay formed through alteration of volcanic ash or tuff in a lacustrine environment. Attempts by

Photo 6. Barber bentonite mine, circa 1900. *Photo from DMG files.*

DMG staff to locate this deposit through correlation of old photographs and aerial photographs have been unsuccessful. This deposit may have been covered up by U.S. Army activities in the area (Tucker and Sampson, 1931; Rapp and others, 1990).

Silver Lake clay mine: The Silver Lake clay mine and related prospects are located in the Avawatz Mountains, about 3 miles east of the Fort Irwin boundary. A pit in the SE4, SE4 of section 18, T15N, R7E, SBBM has been mined and a prospect is located in the NE4 of the SW4. A bentonite bed 20 feet thick is exposed at the mine and is overlain by poorly sorted fanglomerate. The clay occurs in tuffaceous lakebed sediments of Miocene(?) age, possibly equivalent to the Barstow Formation, and strikes N70°W and dips 60°NW. The bentonite is greenish-gray in color, exhibits a crackly, popcorn weathered surface and probably formed from in situ alteration of volcanic ash or tuff in a lacustrine environment. X-ray analysis by DMG shows the clay contains montmorillonite, calcite and quartz. Several hundred tons of material have been mined (Rapp and others, 1990).

Pink Lady prospect: The Pink Lady prospect is located on the east slope of the Soda Mountains, three-quarters of a mile north of Interstate 15 at the Zzyxx Road overpass in the NW4, section 21, T13N, R8E, SBBM. The gently dipping bed of pink bentonite is about 3 feet thick and is exposed for 300 feet in the mine area. The clay is part of tuffaceous lakebed sediments equivalent to the Miocene Barstow Formation which are largely concealed beneath poorly sorted colluvium and fanglomerate. X-ray analysis by DMG indicates the clay contains montmorillonite (possibly sepiolite) and zeolite. This material formed from in situ alteration of volcanic ash or tuff. Two railcars of bentonite were mined in 1956, the mine has been idle since. Workings consist of a 40-foot adit and numerous dozer cuts (DMG Mineral Property Report Files).

Pink Lady mine: The Pink Lady bentonite mine is located about 4 miles southeast of Lenwood (near Barstow) in the NW4, SE4, section 4, T8N, R2W, SBBM. The pinkish bentonite occurs in a sequence of probable Miocene sediments and tuff (Barstow Formation?) uplifted by intrusive diorite and was formed by in situ alteration of tuffaceous sediments. The clay is reddish-pink, plastic, and contains grains of sanidine, biotite, and mafic minerals. X-ray analysis by DMG indicates the clay contains montmorillonite, cristobalite, potassium feldspar, and calcite with possible zeolite and dolomite. Workings consist of an open pit that is currently idle. U.S. Tile used the clay for viscosity control in their roofing tile mix (DMG Mineral Property Report Files).

Robertson clay mine: The Robertson clay mine is located in the S2 of section 32, T5N, R2W, SBBM, about 4 miles east of Apple Valley, north of Highway 18 in Deadman's Dry Lake. Montmorillonite clay occurs in Quaternary playa sediments with silt and sand. The clay is relatively free of soluble salts that contaminate other playa deposits. Minable clay thickness averages 16 feet. Approximately 2,000,000 cubic yards of clay were removed from this pit for the construction of Cedar Springs Dam. In 1986 this clay was used by U.S. Tile for viscosity control in tile mixtures. The property owners estimate reserves at 1,000,000 tons (Ely, 1982).

Gunn mine: The Gunn bentonite mine is located in the SE4, NW4 of section 22, T10N, R2E, SBBM about 5 miles northeast of Yermo. The clay is white, nearly flat-lying and mapped as Miocene shale and sandstone (Dibblee, 1970). Thickness varies from 2 to 4 feet and the clay is a few feet below a basal caliche bed of overlying fanglomerates and gravel. The bentonite is a high magnesium montmorillonite and was used as a sealant and viscosifier. The quarry was mined in the 1950s and 1960s, with production exceeding a few thousand tons. The site is now part of a county-owned archaeologic preserve (DMG Mineral Property Report Files).

Bentonite prospect: A bentonite mine is located about 1.5 miles east of the Gunn Mine, 3 miles west of Lake Dolores in the NW4, SE4 of section 14, T10N, R2E, SBBM. The area is mapped as Quaternary older alluvium (Dibblee and Bassett, 1966), but the bentonite is most likely derived from older Tertiary sediments. The bentonite is gray-green and exhibits a crackly, popcorn weathered surface. Alteration trends N-S and dips 40°E. The clay was probably formed by in situ alteration of rhyolite tuff. A haulage adit can be traced for at least 25 feet and spoils indicate production of at least 500 tons (DMG Mineral Property Report Files).

Bentonite mine: Bentonite is exposed for about one-half mile just north of Interstate 15, 3.5 miles southwest of Lake Dolores, on the south side of an offset hill (Photo 7). The main workings are in the S2, NE4 of section 26, T10N, R2E, SBBM on the Harvard Hill 7.5-minute quadrangle. The geology of the workings is mapped as tuffaceous Miocene sediments (Dibblee and Bassett, 1966). Silty, tuffaceous gray-green bentonitic clay is interbedded with rhyolite tuff. Bedding trends E-W and dips about 30°N. X-ray analysis by DMG indicates montmorillonite, calcite and quartz. Underground workings are caved or have been filled in. Estimated production may be as high as a few thousand tons, based on the size of tailings (DMG Mineral Property Report Files).

Pacific bentonite mine: The main workings of the Pacific bentonite mine are in the NW4 of section 31, T28S, R41E, MDBM, 6 miles north of Johannesburg in the Summit Range. Bentonite occurs in the Pliocene Bedrock Spring Formation interlayered with pinkish-gray tuff, ash-flow tuff and agglomerate. The thickness of the bentonite varies from 2 to 15 feet. The beds are folded and discontinuous along strike, which is roughly E-W and dip is north. Bentonite was formed by in situ alteration of volcanic ash or tuff in a lacustrine environment. Worked intermittently from the 1930s to 1972, mined bentonite has been used for pond sealant, cleansing preparations, drilling mud and foundry sand binder (DMG Mineral Property Report Files).

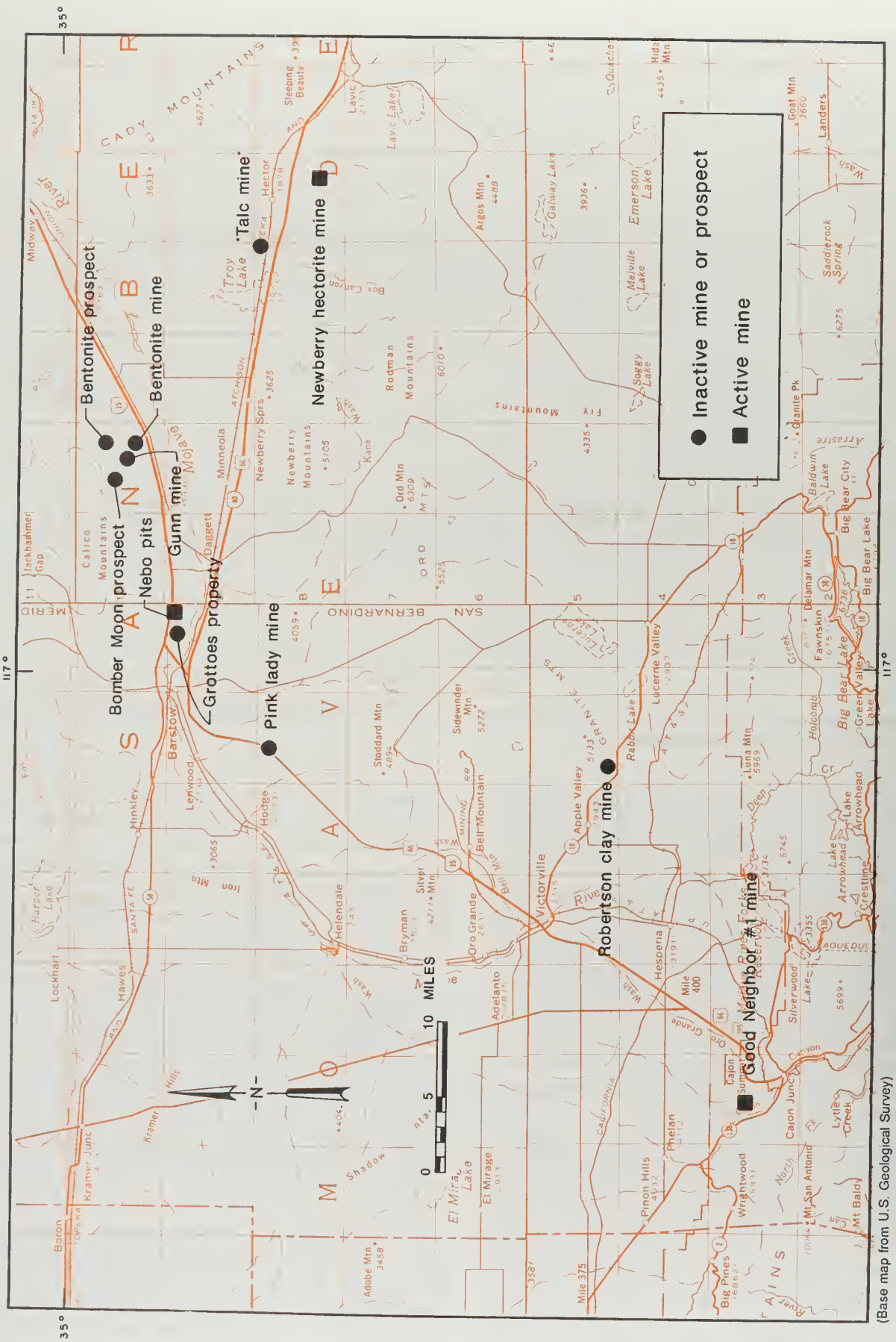
Photo 7. Workings in old, unnamed bentonite mine (Bentonite mine in text) in the east end of the Calico Mountains, near Yermo, San Bernardino County. *Photo by Mike Silva.*

Kingston Wash mine: The Kingston Wash bentonite mine is located in the S2 of the SW4, section 26, T18N, R9E, SBBM, about 6 miles southeast of Tecopa Pass. The white to light-gray bentonite occurs in Tertiary lake-bed deposits, interbedded with sandy clay beds and overlain by a dolomite breccia. The beds strike E-W and dip 20°N. Exposure of the clay is terminated on the northwest by a volcanic ridge and on the southeast by faulting and erosion. X-ray analysis by DMG indicates the clay consists of sodium montmorillonite with minor opal. The clay was formed in situ by alteration of volcanic ash in a lacustrine environment. Now idle, the mine was operated in the late 1980s by American Colloid Company, which used the clay for high-value pharmaceutical fillers (Bezore and Joseph, 1987).

Newberry hectorite mine: Hectorite, a magnesium-lithium montmorillonite, is mined by Rheox, Inc. (formerly N.L. Chemicals, Inc.) from a pit located in the SW4 of section 26, T8N, R5E, SBBM, on Hector Road 2.5 miles south of Interstate 15. Hectorite occurs along a northwest-trending fault zone for about 5 miles from the pit. The clay is white, waxy, and the dominant clay mineral in a series of Pliocene lakebeds. Bentonite is up to 100 feet thick, averages 10 to 12 feet, and is absent in places. These deposits are interbedded with lake sediments and hot-springs-derived cherty travertine, which provides structural control. The Pisgah fault displaces the hectorite beds which are overlain by 70 feet of basalt flows. Hectorite is unique, formed by alteration of ash and vitric tuff by lithium-rich hot springs in a lacustrine environment. Where hot spring activity diminished, volcanic materials were altered to zeolites. X-ray analysis by DMG indicates the clay contains hectorite and calcite. Hectorite is selectively mined, air dried, then processed into specialty, high-value fillers used for cosmetics, paint and beverage clarification (Sweet, 1980; Ames and others, 1958; DMG Mineral Property Report Files).

Balch prospect: A 10-foot-thick bed of bentonite was reportedly located in section 10, T12N, R11E, SBBM, 10 miles north of Balch in the Old Dad Mountains. The deposit, prospected by several open cuts, was exposed for 700 feet. A chemical analysis of the clay shows high silica and aluminum (Tucker and Sampson, 1931). This location has not been verified.

Smith prospect: Also referred to as the Hunger and Phillips and the Black Prince Group, this deposit is reportedly located in section 26, T6N, R14E, SBBM, 5 miles north of Chambless. Four-to 7-foot-thick beds of white to pink bentonite are reported to occur in basalt. These are probably interbedded,



(Base map from U.S. Geological Survey)

Figure 8. Bentonite mines and prospects in western San Bernardino County.

altered tuffs. Development consists of a number of open pits and trenches. The clay was used for a conditioner in chicken and cattle feed and for beauty face packs. This location has not been verified (Tucker and Sampson, 1943).

Bomber Moon prospect: The Bomber Moon prospect is located in the SW4, SE4 of section 17, T10N, R2E, SBBM, 4 miles northeast of Yermo in the east Calico district. A 1- to 5-foot-thick bed of bentonite is exposed for 4,000 to 5,000 feet. Workings consist of a 40-foot shaft driven into Miocene lacustrine sediments and a small open pit. X-ray analysis by DMG of a sample taken from a small dump reveals the material is composed of montmorillonite and zeolite. The clay was used as a sealant and viscosifier (Wright and others, 1953; Dibblee, 1970; GSA Resources files).

Brown mine: Bentonitic clay reported south of Vidal occurs in Plio-Pleistocene non-marine sediments and was used for trace mineral carrier in feed stock. The location was described in 1953 as section 13, T1S, R23E, SBBM; however, the corrected location from GSA Resources is the N2 of section 24 (Wright and others, 1953; GSA Resources files).

U.S. Bentonite prospect: Bentonite is reported in the NW4 of section 32, T28S, R41E, MDBM, north of Randsburg. The deposit is described as similar to Pacific bentonite, which occurs in the Pliocene Bedrock Spring Formation interlayered with pinkish-gray tuff, ash-flow tuff and agglomerate. This location has not been verified (Wright and others, 1953).

Grottoes property: The Grottoes property, under claim by GSA Resources, is located in the SE4 of section 2, T9N, R1W, SBBM, about 1 mile north of the U.S. Marine Corps supply center at Nebo. Prospects are located in Miocene or Oligocene limestone and tuff that strike E-W and dip 30°S. The clay is white and creamy and the alteration product of rhyolite tuff (Photo 8). Analysis by DMG indicates the clay contains montmorillonite (possibly sepiolite), zeolite, and quartz. Workings consist of three adits and a large open cut (DMG Mineral Property Report Files).

Photo 8. Altered tuff containing calcium bentonite exposed in cut on the Grottoes property, near Barstow, San Bernardino County. *Photo by Mike Silva.*

Good Neighbor #1 mine: The Good Neighbor #1 mine is operated by Star Clay Industrial Minerals and is located in the SW4 of section 16, T3N, R6W, SBBM, about 3 miles northwest of Cajon, and 1 mile east of Highway 138. The area is mapped as Miocene Punchbowl (?) Formation of Cajon Valley by Bortugno and Spittler (1986). The clay probably formed in situ from volcanic material in a freshwater lake. Identified as a high aluminum non-swelling montmorillonite, the clay has been used for ceramics, mud jacking, pond sealants and tile. U. S. Title Company mines clay from the pit for use in their title mix. The operator estimates reserves at 1,000,000 tons (DMG Mineral Property Report Files).

Nebo pits: Brubaker-Mann operates two small bentonite pits in the NE4 of section 1, T9N, R1W, SBBM, about 2 miles north of the U.S. Marine Corps supply center at Nebo. The gray-white, plastic, swelling clay is mapped as Oligocene or Miocene andesite and tuff breccia by Dibblee (1970) and grades into limestone to the west. Bedding strikes N-S and dips 30°W. X-ray analysis by DMG indicates the clay contains montmorillonite, opal, quartz and feldspar. The clay was formed by in situ alteration of volcanic tuff in a lake. Two small open pits are operated by the company. The mined material is used as a trace mineral carrier for animal feed supplements (DMG Mineral Property Report Files).

"Talc mine": A pit worked for bentonitic clay is located in the NE4 of section 1, T8N, R4E, SBBM, about 2 miles east of the southeast end of Troy Lake in the south end of the Cady Mountains. Greenish-gray, soft, massive bentonitic clay occurs at the base of a Pleistocene fanglomerate and gravel and is probably derived from Miocene tuffs. Several small pits have been excavated (Dibblee and Bassett, 1966). This location has not been verified.

Riverside County

Palen Mountains prospect: Beds of bentonitic clay are located in sections 24 and 25, T5S, R17E, SBBM, on the southwest flank of the Palen Mountains. Thin beds (1 inch to 1 foot thick) of buff-colored silt and clay, with a bed of caliche, are overlain by angular gravels and exposed for about 1 square mile. These strata are flat-lying and undisturbed. The clay was formed in situ by alteration of volcanic ash in a lake. The deposit has been explored through several shallow prospect pits (Saul and others, 1971).

San Diego County

General Petroleum mine: Also known as the Mosto Ranch deposit, the General Petroleum mine is located in the N2 of section 30 and the NW4 of section 29, T18S, R1W, SBBM, on the south side of Otay Valley, 3 miles east of Otay. Bentonitic clay, locally known as "otaylite," occurs in the middle to late Pliocene San Diego Formation. Clay occurs in six or more beds, 2 to 4 feet thick, and is interbedded with arkosic sandstone. The clay is white cream to pale pink, slightly swelling, and has a soapy texture when wet. Impurities include quartz, sericite, orthoclase feldspar and iron minerals. High-grade clay underlies and area of 1.3 square miles. The clay was formed by in situ alteration of volcanic ash in a marine environment. Tens of thousands of tons of clay were mined in the 1920s from this deposit. The clay can be activated with acid and was used for cleaning petroleum products. In addition, the clay has proved suitable for specialty oil well drilling mud, paint fillers, water softening compounds and cleaning compounds (Weber, 1963; Cleveland, 1960).

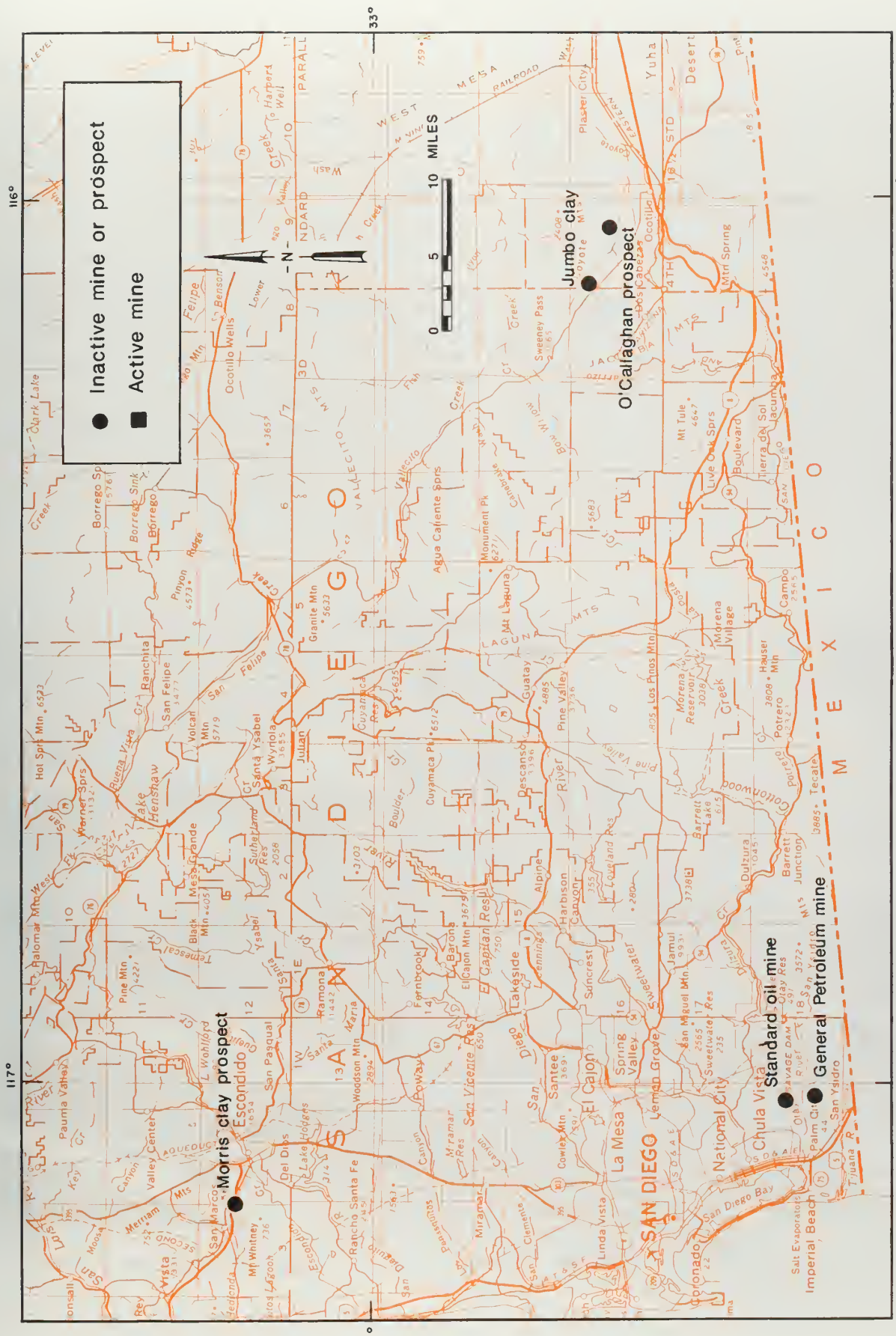
Morris clay prospect: The Morris bentonite prospect is located in the SW4 of section 18, T12S, R2W, SBBM, about 2 miles southeast of San Marcos. Bentonite occurs in a bed at least 30 feet thick that forms a round hill in a saddle between ridges of tonalite. The clay is greenish, impure and weathers to a crackly, popcorn texture. A mill was constructed in 1928, but attempts to use the clay for brick and ceramics were unsuccessful (Weber, 1963).

Schier clay prospect: The Schier clay prospect is located in the NE4 of section 23, T10S, R4W, SBBM, about 2 miles west of Bonsall. Dark grayish-brown, impure bentonite is exposed over one acre. Thickness ranges from a few inches to a few feet. Bentonite occurs in Tertiary sediments overlain by unaltered tuff and dacite flows. The area has been prospected by numerous dozer cuts (Weber, 1963).

Standard Oil mine: The Standard Oil mine, also known as the Filtrol mine, is located in the SW4 of section 17 and the SE4 of section 18, T18S, R1W, SBBM, on the north slope of Otay Valley, 3 miles east of Otay. Bentonitic clay, locally known as "otaylite," occurs in the middle to late Pliocene San Diego Formation. The principal clay bed averages 3 feet thick and in some exposures is 4 or more feet thick. The clay is white cream to pale pink, slightly swelling, and has a soapy texture when wet. Impurities, as low as 4 percent, include quartz and sericite. High - grade clay underlies an area of 1.3 square miles. The clay was formed by in situ alteration of volcanic ash in a marine environment. Tens of thousands of tons of clay were mined from this pit, which has faces over 3,500 feet long over several acres. This deposit was worked by the General Petroleum Company in 1925, the Standard Oil Company from 1926-1944, and the Filtrol Company in 1947 and 1948. The clay can be activated with acid and was used for cleaning petroleum products. In addition, the clay has proved suitable for specialty oil well drilling mud, paint fillers, water softening compounds and cleaning compounds (Weber, 1963; Cleveland, 1960).

Imperial County

Jumbo clay: The Jumbo clay deposit is reported in sections 6, 7 and 8, T16S, R9E, SBBM, in the Coyote Mountains, about 5 miles north-northwest of Dos Cabesos. Extensive deposits of high-silica, low-alumina clay underlie much of the Coyote Mountains. These deposits are in the Pliocene marine Imperial Formation and occur as low-lying erosional remnants. This location has not been verified (Morton, 1977).



(Base map from U.S. Geological Survey)

Figure 9. Bentonite mines and prospects in San Diego and western Imperial counties.

Cal-Min-Co mine: The Cal-Min-Co deposit is located in the middle of the S2 of section 20, T14S, R12E, SBBM, near the southeast tip of Superstition Mountain, about 16 miles west-southwest of Brawley. Pale, grayish-brown clay in the Pleistocene Brawley Formation strikes about N30°E and dips about 5°NW. The clay is 20 feet thick and crops out over many acres. The clay has not been identified, but contains calcium carbonate and other soluble salts. Mined from 1951 to the late 1970s, several thousand tons of clay were sold locally for cattle feed supplement and soil conditioner. The mine is developed by an open pit (Morton, 1977).

O'Callaghan prospect: The O'Callaghan prospect is located in the SE4 of section 14, T16S, R9E, SBBM, about 3 miles north-northwest of Ocotillo, at the extreme southeastern base of the Coyote Mountains. Ten to 30 feet of yellow-gray clay occurs in the Pliocene Imperial Formation. In the mine area, the clay bed strikes N60-80°E and dips 10-20°SW. Production is undetermined but was small. The clay was used locally as a livestock feed supplement (Morton, 1977).

14. Production

Fuller's earth was first produced in California in 1899. From that time until 1919, production was mainly from deposits in Calaveras and Solano counties. Later, deposits in Los Angeles, San Diego and Kern counties were discovered and mined. It is ironic that most of these deposits, notably those in Calaveras and Solano counties, were not well described and are not accurately located today (Lamar, 1953).

The discovery of the high-quality Cheto bentonite deposit in Arizona in the 1920s and the development of synthetic zeolites displaced California fuller's earth and contributed to the closure of many mines. Bentonite producers responded by developing specialty and absorbent products which make up much of the market today. As of June 1990, there are 11 active mines operated by 10 companies that mine bentonite or fuller's earth. Of these, only three pits reported mineral production to the U.S. Bureau of Mines for 1988. Mines no longer active in 1990 that had reported mineral production in

Photo 9. Lightweight aggregate plant operated by Pacific Lightweight Products Company at Frazier Park, Ventura County. Bentonite is expanded by heating in the kilns at left. *Photo by Dan Eyde.*

1988 include the Kingston Wash mine in San Bernardino County. See maps of prospects for location and names of active mines.

The U.S. Bureau of Mines mineral production statistics are collected by questionnaires answered by the respondent companies. The 1988 U.S. Bureau of Mines statistics classify Lowes Southern Clay's clay production as bentonite and Excel Minerals' clay production as common clay. Lowes and Excel Minerals produce an absorbent kitty litter from the McClure member and the Gould member of the Monterey Formation, respectively. These units are nearly identical and consist of diatomaceous shales altered to porcelanite, a porous, silica-cemented shale (Vredenburgh, 1990). Anaylsis by DMG indicates the shale is composed of opal, quartz, plagioclase, illite and smectite (possibly a mixed-layer illite-smectite). The physical properties of this shale are not derived from dominant smectite; thus, this material does not meet the definition of bentonite for the purposes of this report.

Adding production of unreported mines and subtracting production of kitty litter, DMG estimates the mine site value of bentonite produced in California at $5,000,000 for 1989. It is important to note that U.S. Bureau of Mines clay value figures reflect mine-site prices. Bentonite reported at $70 a ton before processing may sell for up to $2 a pound ($4,000 a ton) after grinding, washing, drying, and activation. Although reported figures may seem low, bentonite is an important part of California's mineral wealth.

15. Utilization and Markets

The unique physical and chemical properties of bentonite and fuller's earth account for the wide variety of markets served by the clay. Bentonite is indispensable as a component of drilling mud. In ceramics, bentonite adds plasticity and strength to the wet mix. Bentonite also increases the strength of foundry molding sand, allowing the mix to hold its shape throughout the entire casting process. The unique structure of bentonite enables its use as a catalyst for petroleum refining and as an adsorbent of impurities from petroleum, wax, and animal and vegetable oils. High-quality bentonite is used to clarify beer, wine and other liquids, and as a filler in pharmaceuticals, paints, paper, ink and cosmetics. Other uses include bonding agents in pelletizing animal feeds, carriers for insecticides, grease absorbents, fillers in rubber manufacture, pond

Photo 10. Incline workings for hectorite at California Talc Company mine, circa 1935. These workings are now part of the Newberry hectorite mine property operated by Rheox, Inc. (formerly N.L. Industries). *Photo from DMG files.*

Photo 11. The Newberry hectorite mine operated by Rheox, Inc. (formerly N.L. Industries). Note the intense white color of the hectorite. *Photo by John Clinkenbeard.*

sealants, adhesives, mortar and cement, and grease manufacture. Bentonite may be treated with organic molecules to increase its thixotropic qualities and with acid to enhance adsorptive qualities.

In California, the market has been dominated by local markets and the availability of specific clay types. California has limited deposits of swelling bentonite, and most bentonite used for well drilling mud comes from out of state. In the early 1900s, most bentonite and fuller's earth produced in California was used for refining petroleum products, cleaning animal and vegetable oils, and as a binder in the foundry and steel industries. As new materials were used for refining and cleaning, industrial uses increased. In 1975, the main uses of bentonite were light-weight aggregate, foundry sand and animal feed supplements (Photo 9).

Economic slowdowns of the early 1980s redefined the California bentonite market. Producers of swelling, high-quality bentonite diversified into the high value-added specialty clay market. These clays are processed to very strict chemical and physical specifications and sell from as little as $.10 a pound for a rheology control extender product for paints to over $2.00 per pound for pharmaceutical-grade, FDA-approved fillers for drugs and cosmetics. Today, the major uses for swelling bentonite include high value-added products for paint, ink, pharmaceuticals and cosmetics, fillers for ceramics, adhesives, plastics and rubber, and carriers for insecticides. Non-swelling bentonite is used for animal feed supplements, water sealants, grease absorbents, pesticide carriers and drilling mud additives.

16. Mining Methods and Beneficiation

Virtually all bentonite is produced by open pit or strip mining methods, although in the past, underground mining was commonly used in high-grade fuller's earth deposits (Photos 10 and 11). Generally, bentonite is mined using scrapers or front end loaders. Crude ore is usually hauled to the processing plant by trucks.

Bentonite is processed by relatively simple beneficiation methods. Crude bentonite, containing up to 30 percent moisture, may be run through a clay slicer to break up large lumps. The clay is then dried in a rotary kiln or fluid bed dryer at about 150 degrees Celsius.

After drying, the clay is ground and screened. Most bentonites are ground until 90 percent pass through a 200 mesh screen. Some fuller's earths used in special applications are ground as fine as 10 microns. Hectorite and some fuller's earths are hydroclassified to remove impurities and then dried and ground. Processed bentonite is blended with additives or treated with acid or organic compounds when required by end users and is shipped in bulk, fiber drums, or bags.

The processing of mineral absorbent products includes drying, crushing and screening to finished product sizes dependent on end use. In these operations, minus 60 mesh fines are discarded as unusable. Absorbents are generally dried or calcined (fired at high temperature). Calcination produces a harder particle that resists degrading into fines during handling and use and increases sorptivity.

17. Events, Trends and Issues

Bentonite producers in California, like producers of other minerals, are affected by market fluctuation production costs and mineral availability. Market fluctuations responding to construction and oil drilling trends directly influence industrial mineral production. Bentonite producers have changed markets in the past, from oil refining materials to high value-added products. Market development and research is an ongoing concern for bentonite producers. It is interesting to note that for the last 3 years, swelling bentonite mined in California has not been used for drilling mud. Large increases in oil well drilling could encourage development of local sources of swelling and non-swelling bentonite.

Absorbent mineral applications, such as liners in landfills, have potential for expansion. Solidifying liquid wastes simplifies transport and disposal. Municipalities in California use landfills for waste disposal, manufacturers use settling ponds for industrial wastes, and heap leach mining operations use liners for heap leach pads. These waste disposal sites must be prepared properly to minimize migration of toxic substances. One method of controlling loss of toxic material is the use of clay liners or bentonite sealants. This may also be a good market for value-added, high-yield clay products. These products may carry some type of performance guarantee and command a high price.

The market for specialty clay products continues to grow. As research continues, more uses will be found for specialty clays, which are clays that have physical and chemical characteristics enhanced by additional processing and/or chemical modification. Engelhard Minerals has developed a white, non-swelling bentonite usable for carrying ink in carbonless carbon paper. Pressure from writing releases the ink. Another market for specialty clays with growth potential is desiccants and filtration aids.

Lightweight expanded clay aggregates are used in the construction industry. Concrete mixes using lightweight aggregates are up to 25 percent lighter than regular mixes, and have increased insulation and fire resistance. Lighter concrete reduces the amount of structural reinforcement required in a building project. Aggregate blocks and roof tiles are also made from expanded clay, lightweight aggregate.

Lightweight aggregates have about 2 percent of the concrete aggregate market in California. This percentage has remained constant for many years and provides the upper limit for future growth in the construction industry. A new market for lightweight aggregate is lightweight roof tiles. This could significantly expand the market for lightweight aggregates.

Availability of deposits is a major concern for bentonite producers. In California, many of the productive bentonite and fuller's earth deposits or major resources are located on federal lands in the California Desert Conservation Area (CDCA). The availability of clay deposits in the CDCA could be constrained by pending legislation and management of environmentally sensitive areas. Existing mines could be shut down and developed deposits may not be permitted to be mined.

A bill was introduced in the U.S. Senate to create new National Parks and Wilderness areas totalling about 7.5 million acres out of a total of 12.1 million acres in the California Desert Conservation Area managed by the U.S. Bureau of Land Management (BLM) (Farney and Taylor, 1986). The wilderness designations in this bill would have a greater impact on mineral resource development in the California desert than those proposed by the BLM under the California Desert Conservation Act of 1980. The California Desert Conservation Act represented the first attempt to identify, inventory, categorize, and determine the highest and best uses of desert resources.

The bentonite producers in California face a number of other major regulatory constraints as well. On August 4, 1989, the U.S. Fish and Wildlife Service exercised its emergency authority to determine the Mojave population of the desert tortoise (*Gopherus agassizii*) to be an endangered species pursuant to the Endangered Species Act of 1973, as amended (Campbell, 1989). Subsequently, on April 3, 1990, the tortoise status was changed to "threatened."

This has some far-reaching effects, particularly in the Mojave Desert of California. The Endangered Species Act protects not only a plant or animal, but its habitat as well. This often leads to a total prohibition of human activities in areas defined as "critical" habitat. Already, the BLM has developed a draft Rand Mountains-Fremont Valley Management Plan (U.S. Bureau of Land Management, 1989) covering 65,000 acres, between California City and Randsburg, adjacent to the nearly 25,000 acres in the Mojave Desert Tortoise Natural Area. The plan, as proposed, would result in nearly 45,000 acres of public land being closed to mineral entry. This would be in addition to the closure to mineral entry of the Mojave Desert Tortoise Natural Area. The areas listed as Desert

Tortoise Habitat cover about half of the California Desert Conservation Area not already closed to mineral entry because of military bases or National Parks.

Another factor affecting mineral availability is the Mining Law of 1872, which defines three categories for minerals: (1) locatable minerals (located by mining claims); (2) leasable minerals (subject to non-competitive prospecting permits and competitive bidding for mineral leases); and (3) salable minerals (competitive bidding for mineral sale). Since the law was intended primarily to regulate the acquisition and development of metallic mineral resources, there have been difficulties in applying the law to industrial minerals like clays. Presently, clays that are uncommon are locatable under the Mining Law of 1872. Those clays deemed to be common are salable under the Materials Act of July 31, 1947. The poorly defined distinction between common and uncommon varieties of clay and other industrial minerals has led to litigation on a number of occasions. In general, an industrial mineral deposit is locatable if it meets the following criteria:

1) It must have a unique property.
2) The unique property must give the deposit a distinct and special value.
3) The value may be for some use to which the ordinary varieties of the mineral cannot be put, or; the material must sell for a higher price than material in other deposits without the unique property (Maley, 1983).

Generally, bentonite clays that meet the specifications for applications like drilling fluids and taconite pelletizing, or which have clearly unique chemical and physical properties, would be locatable. Currently, a clay used to make structural brick or tile would be considered a common and not locatable clay. In comparison, hectorite mined near Hector, California, by Rheox, Inc. (formerly N.L. Chemicals, Inc.) would be classified as an uncommon variety, with all other clay deposits falling somewhere in between.

It may be possible to use other criteria to define common and uncommon minerals. Bentonitic clays, or mineral products that are sold in bulk as packaged processed minerals, with a unit value higher than that of processed API Wyoming bentonite, could also be characterized as uncommon mineral varieties because of their high value. A good example might be mineral products used as kitty litter, which must meet specifications covering water absorption, attrition resistance, color and bulk density to compete in an industry in which the product can sell for hundreds of dollars per ton at retail. In the past, bentonite mined for expanded aggregate has been classified as common clay, and siliceous shale mined for kitty litter has been classified as bentonite by the U.S. Bureau of Mines.

It appears that some sentiment exists in the U.S. Congress for the repeal or revision of the Mining Law of 1872. In March 1989, the U.S. General Accounting Office submitted a report to Congressman Nick Rahall, II, Chairman, Subcommittee on, Mining and Natural Resources, titled *Federal Land Management : The Mining Law of 1872 Needs Revision.* The report recommended removing the patent provision from the Mining Law and replacing the annual assessment work requirement with a payment to the federal government. Of interest was the fact that of the companies contacted in the preparation of the report, half were major clay mining companies. Changes in the mining law would certainly have an impact on many of the bentonite-mining operations in California.

Recently there has been growing concern about health consequences of crystalline silica, and the ramifications of possible regulation of such emissions on mining, construction and agricultural operations. The term "crystalline silica" refers to the quartz group of minerals, which has different crystal forms within it, all of which are composed of the compound silicon dioxide. Airborne quartz dust was identified as a source of the respiratory disease, silicosis, over two generations ago. In 1987 the International Agency for Research of Cancer of the World Health Organization classified fine-grained crystalline silica as probably carcinogenic to humans (Miles, 1990). With this listing, crystalline silica became a regulated substance under the Federal Hazard Communication Standard, a worker right-to-know regulation administered by OSHA. Federal guidelines mandate that all products containing 0.1 percent or greater crystalline silica must be labeled in compliance with the Hazard Communication Act.

In 1988, crystalline silica was added to the California list of carcinogens under Proposition 65, the Safe Drinking Water and Toxic Enforcement Act of 1986. Crystalline silica is present in many of the mineral commodities produced in California. Typically, bentonitic clays contain 1 to 5 percent quartz, which would subject them to regulation under Proposition 65. Clay producers should be aware of potential legal liabilities under these regulations.

Bentonite producers, like much of the mineral industry, are affected by public land and environmental policy on the exploration, development, and production of minerals. In addition, limited market expansion and product competition can have a negative impact on bentonite production. With reasonable land use and environmental regulations assuring an adequate supply of high-quality raw material, the bentonite industry will continue to be a small but important contributor to California's mineral wealth and independence.

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GLOSSARY OF SELECTED CLAY TERMS

Acid-activated bentonite: high-calcium bentonite treated with acid to enhance sorptive properties.

Bentonite: a clay consisting essentially of montmorillonite, regardless of origin or occurrence, and whose physical properties are dominated by this clay mineral.

Ca-, non-swelling bentonite: dominantly calcium montmorillonite.

Fuller's earth: term derived from first major use of absorbing grease and dust from natural wool and cloth. In the United Kingdom, fuller's earth is calcium montmorillonite; in the U.S., it is any natural material used to decolorize oil and purify to an extent to be of commercial value, usually calcium montmorillonite or attapulgite.

Na-, swelling bentonite: dominantly sodium montmorillonite.

Na-exchanged bentonite: high-calcium bentonite that has had the sodium exchanged synthetically to enhance sorptive properties.

Naturally active bentonite: bentonite that exhibits naturally occurring sorptive properties.

Organophyllic bentonite, organoclay: usually high sodium bentonite treated with cationic organic material to create special properties.

Southern bentonite: calcium bentonite occurring in U.S. states bordering the Gulf of Mexico.

Volcanic clay, soap clay, mineral soap, bleaching, and absorbent clays and earths: loosely used synonyms for bentonite.

White bentonite: a high-brightness and white calcium bentonite.

Wyoming, Western bentonite: sodium bentonite of western USA and Wyoming (from O'Driscoll, 1988).